Assessing the ecological risk of mercury exposure to piscivores

- Persistent and highly mobile toxicant, bioaccumulates in top predators, compromises productivity

- Current risk assessment models inadequate for producing regulatory endpoints

State plan aims to cut mercury pollution

MADISON, Wis. (AP) — The state Department of Natural Resources has introduced a proposal to reduce airborne mercury pollution in Wisconsin.

While industry representa-

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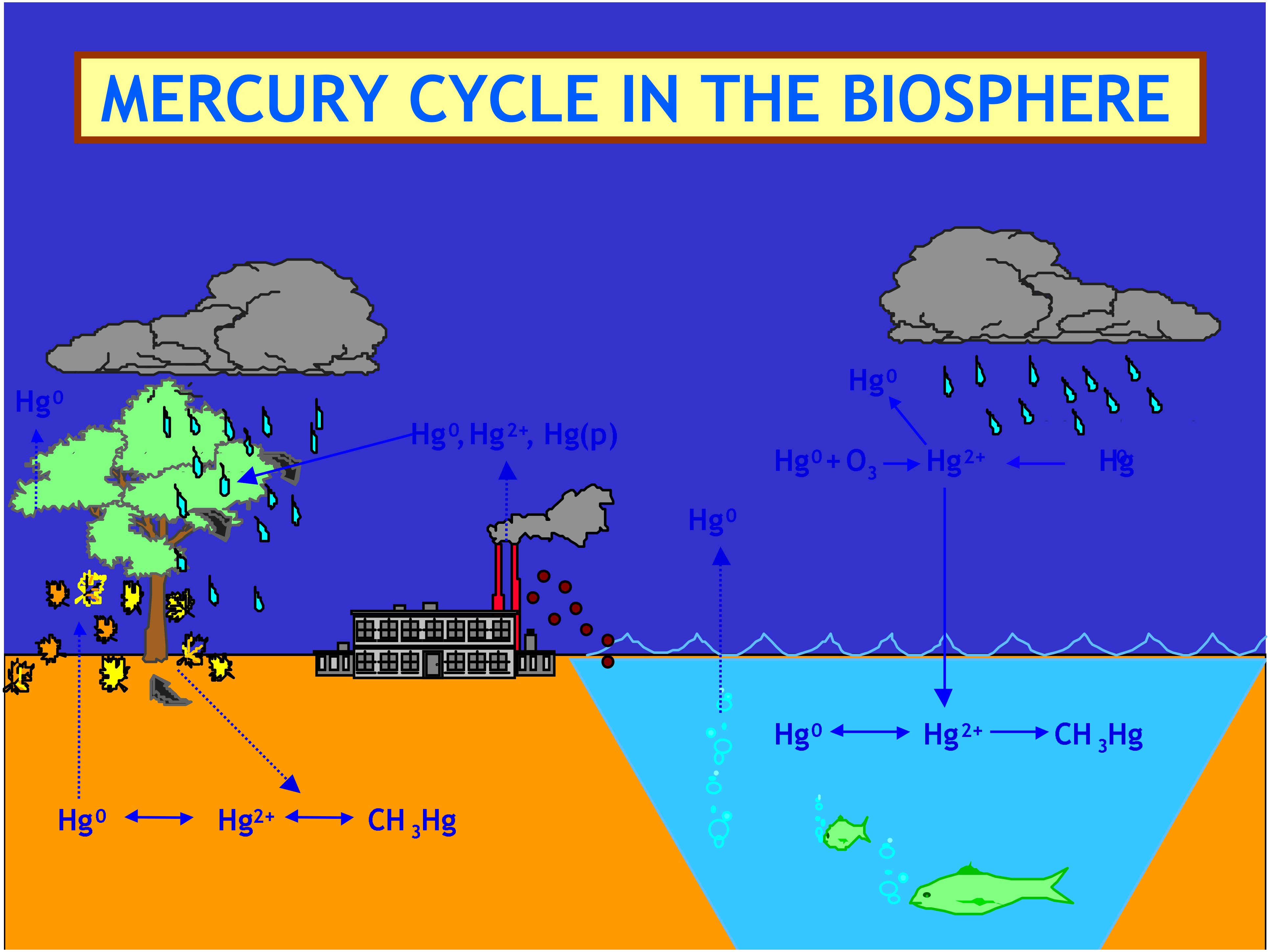
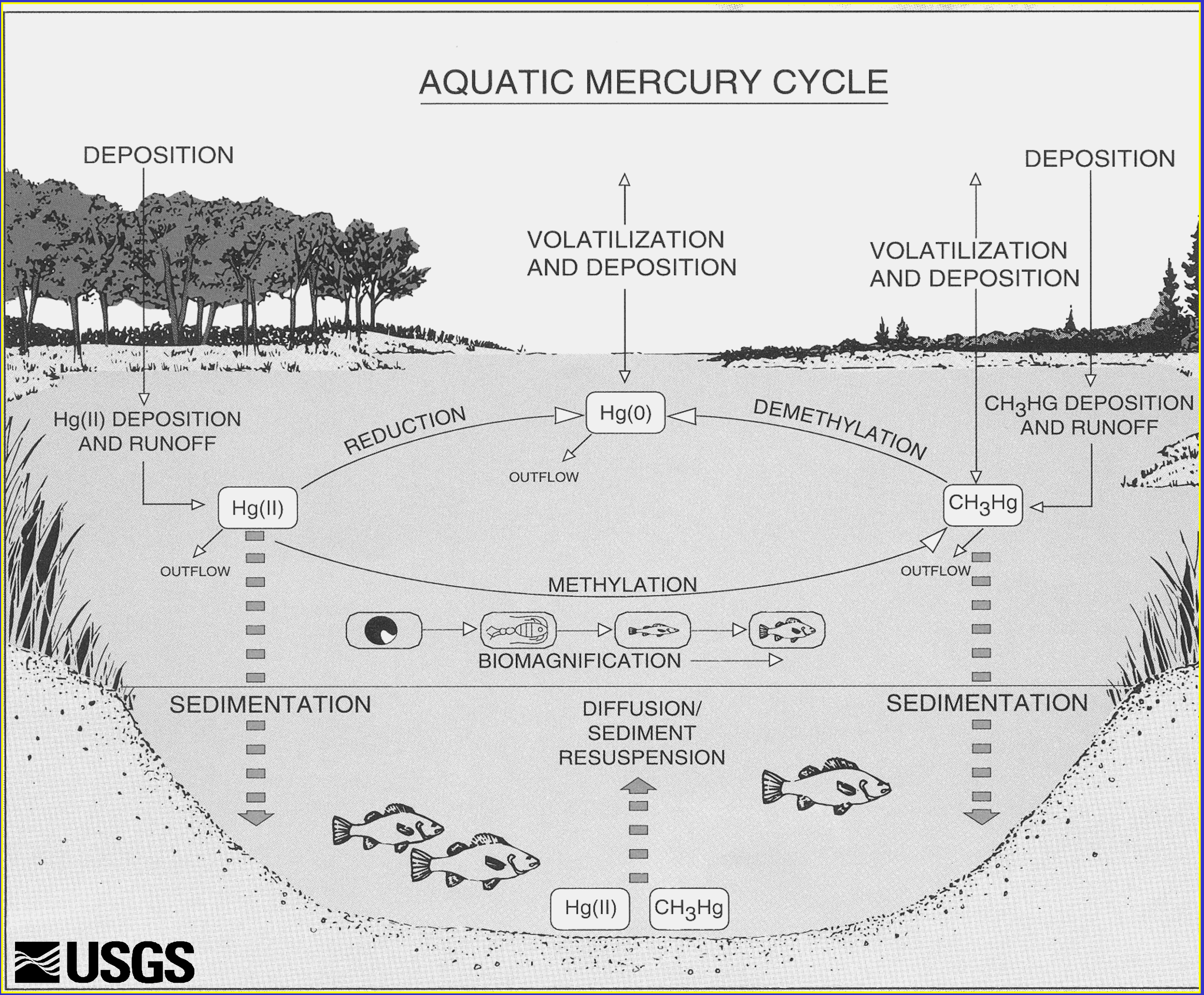

MERCURY CYCLE IN THE BIOSPHERE
Hg^0
Hg^0, Hg^{2+}, Hg(p)
Hg^0
$Hg^0 + O_3 \rightarrow Hg^{2+} \leftarrow Hg^0$
Hg^0
$Hg^0 \leftrightarrow Hg^{2+} \rightarrow CH_3Hg$
$Hg^0 \leftrightarrow Hg^{2+} \leftrightarrow CH_3Hg$



Source: USGS FS-216-95

Common Loon/Mercury Risk Assessment

US Geological Survey, Wisconsin Department of Natural Resources, University of Wisconsin

Photo credit: Woody Hagge

Why Common Loon?

- Sensitive to effects of mercury
  - altered behavior, increased chick mortality
- At risk species
  - high trophic level
  - long-lived
  - obligate piscivore

Photo by Woody Hagge

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Relative Rates of Fish Consumption

Organism	Daily consumption of fish	
	g/individual	g/individual/kg
Adult female human (U.S.)[a]		
Median	31	0.6
95th percentile	110	2.2
Common loon[b]		
Chick (first 11 weeks)	400	220-410
Adult	960	190

[a]USDA Continuing Surveys of Food Intake by Individuals (1989-1991).
[b]Barr 1996.

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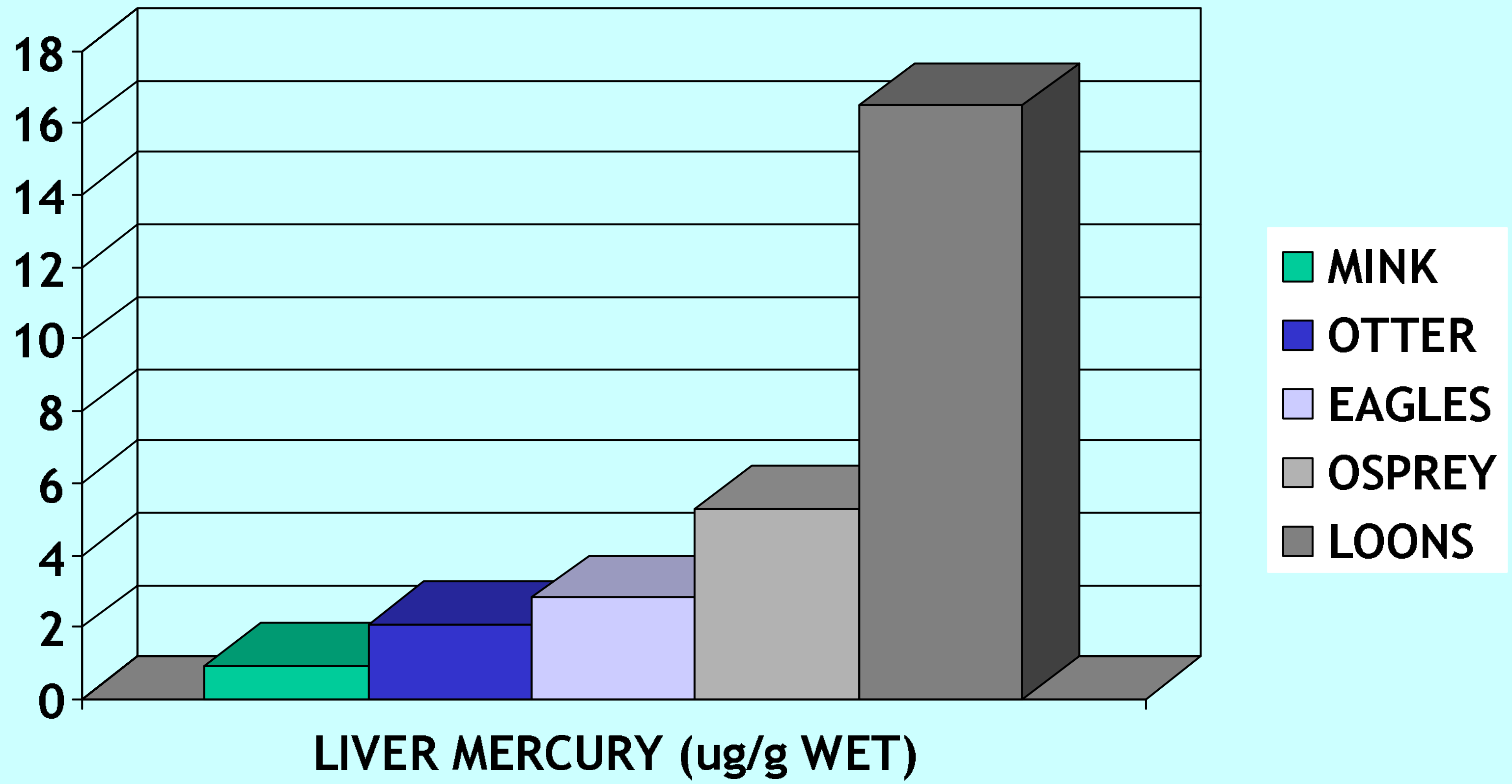
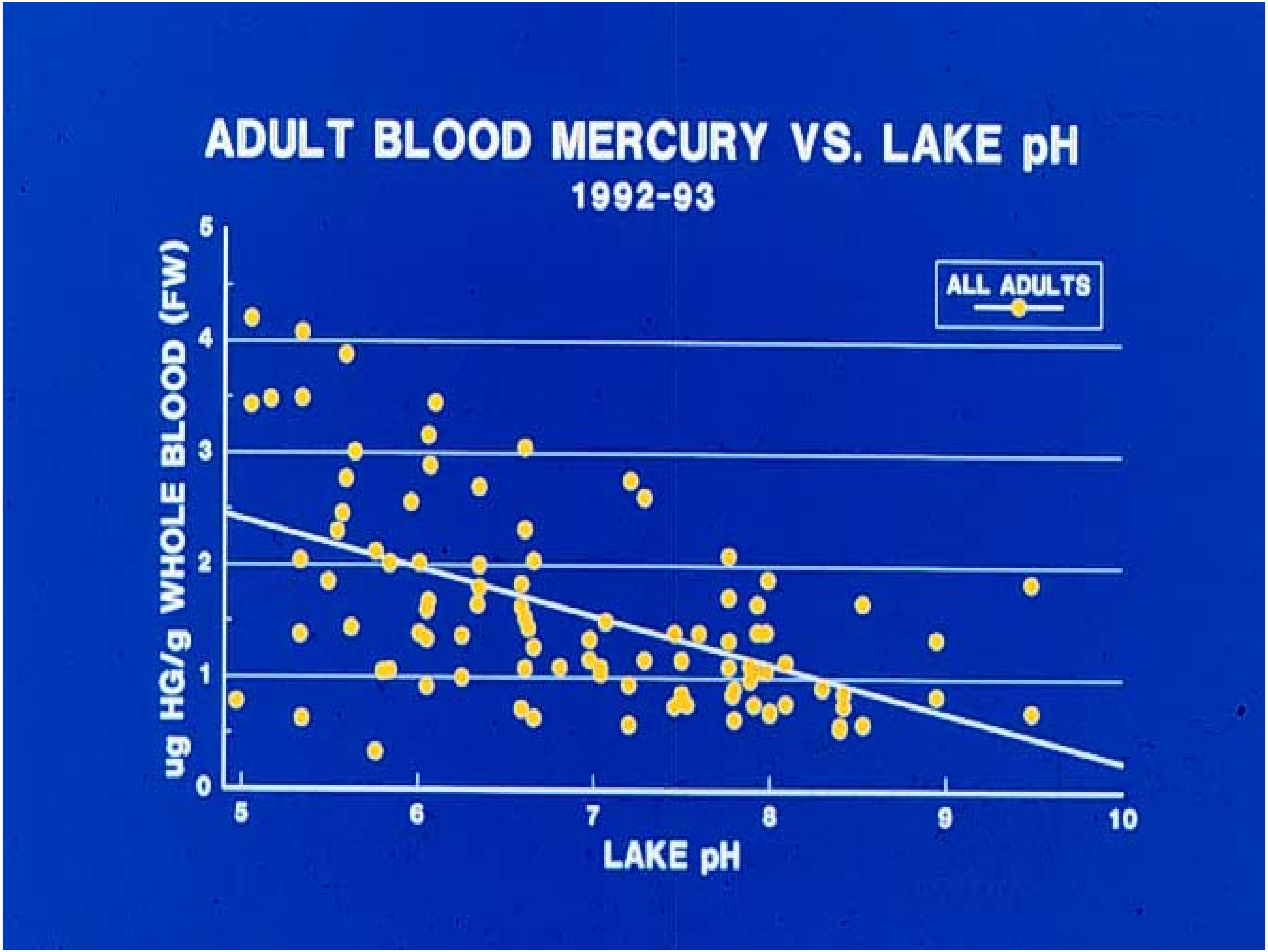
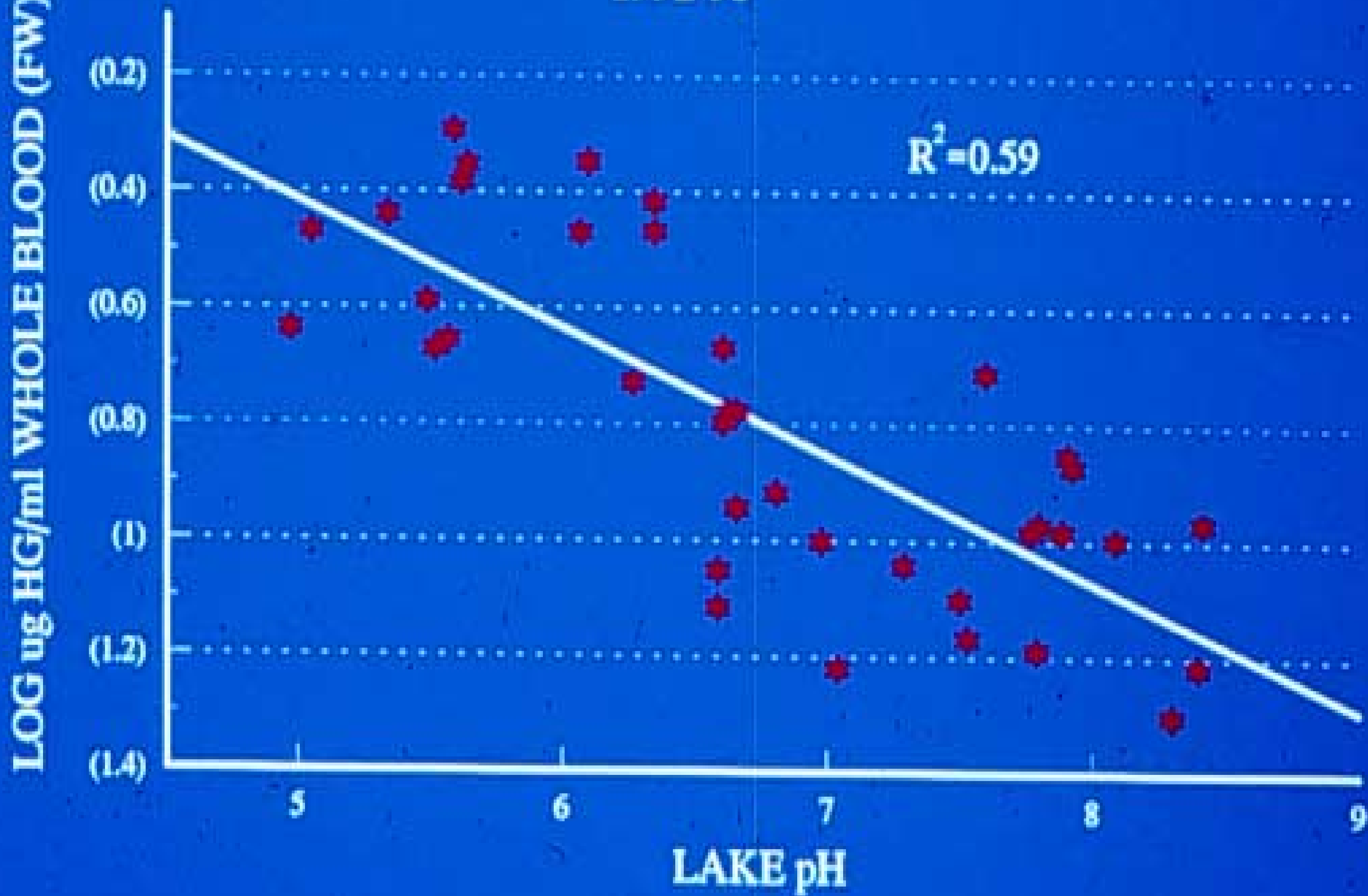
PISCIVOROUS WILDLIFE HG EXPOSURE IN WISCONSIN

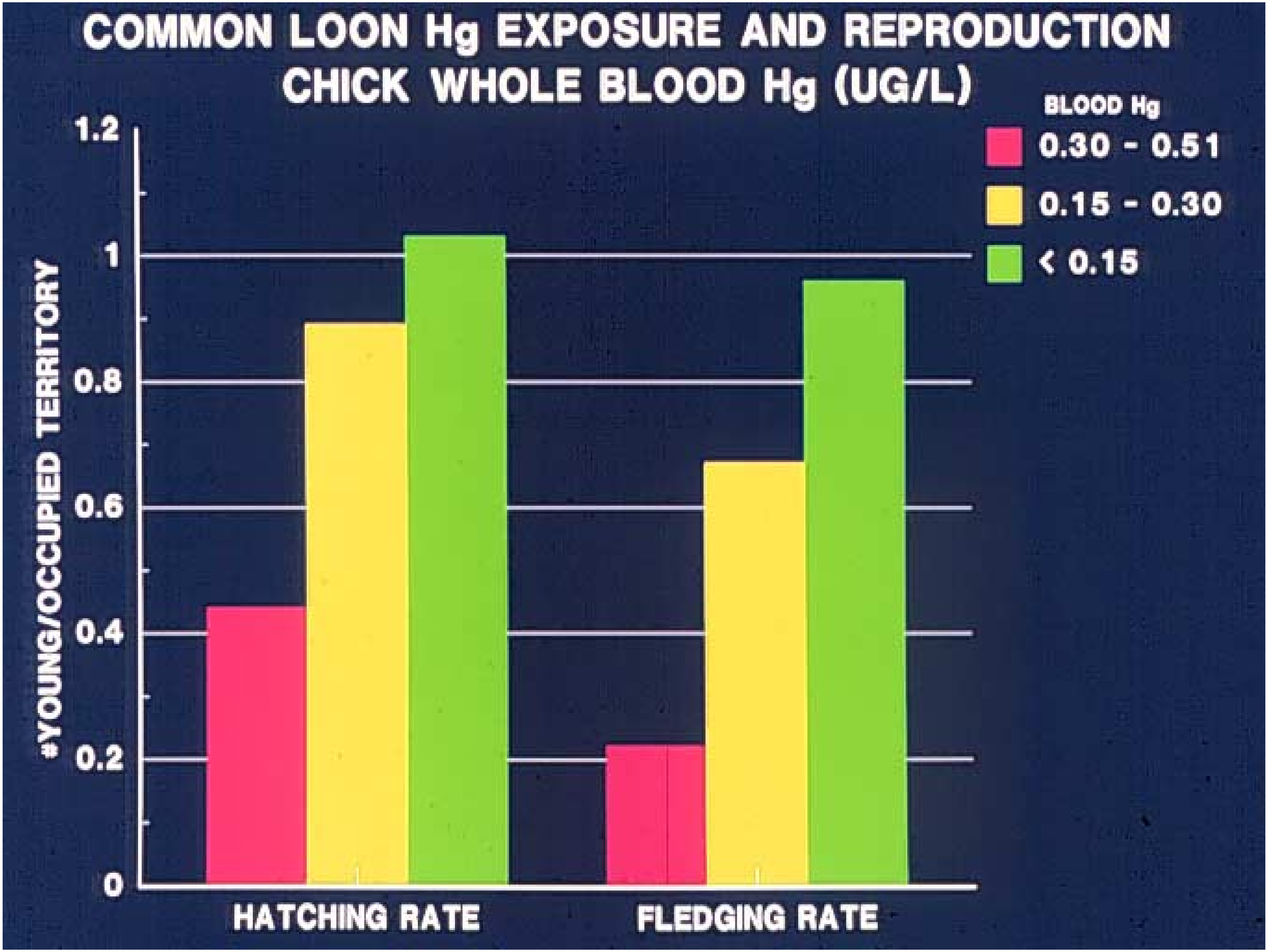


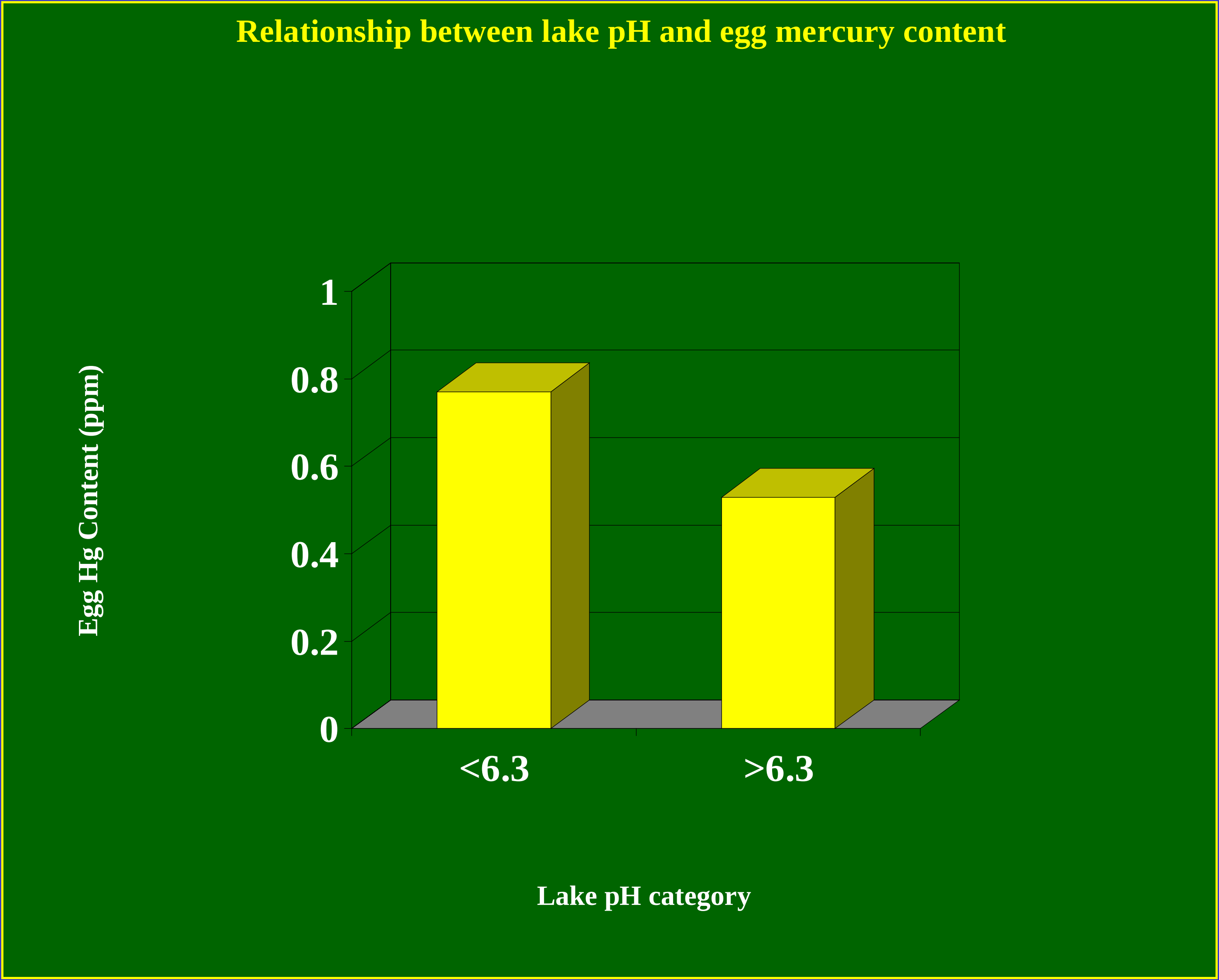
Source: WI Wildlife Contaminant Data Base, 1985-1995


ADULT BLOOD MERCURY VS. LAKE pH
1992-93
ALL ADULTS
ug HG/g WHOLE BLOOD (FW)
0
1
2
3
4
5
5
6
7
8
9
10
LAKE pH

LOG CHICK BLOOD HG
VS. LAKE pH
1992-93




COMMON LOON Hg EXPOSURE AND REPRODUCTION
CHICK WHOLE BLOOD Hg (UG/L)
BLOOD Hg
0.30 - 0.51
0.15 - 0.30
< 0.15
#YOUNG/OCCUPIED TERRITORY
1.2
1
0.8
0.6
0.4
0.2
0
HATCHING RATE
FLEDGING RATE


Relationship between lake pH and egg mercury content
Egg Hg Content (ppm)
1
0.8
0.6
0.4
0.2
0
<6.3
>6.3
Lake pH category

Loon husbandry

UMESC Capabilities

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General objectives

1. develop a mechanistic model to predict tissue concentrations as a function of dietary exposure.

2. quantify mercury exposure associated with negative effects on loon chick survival and fitness.

atmospheric Hg (Hg^0)

methylation

fish tissue [Hg]

INTEGRATING

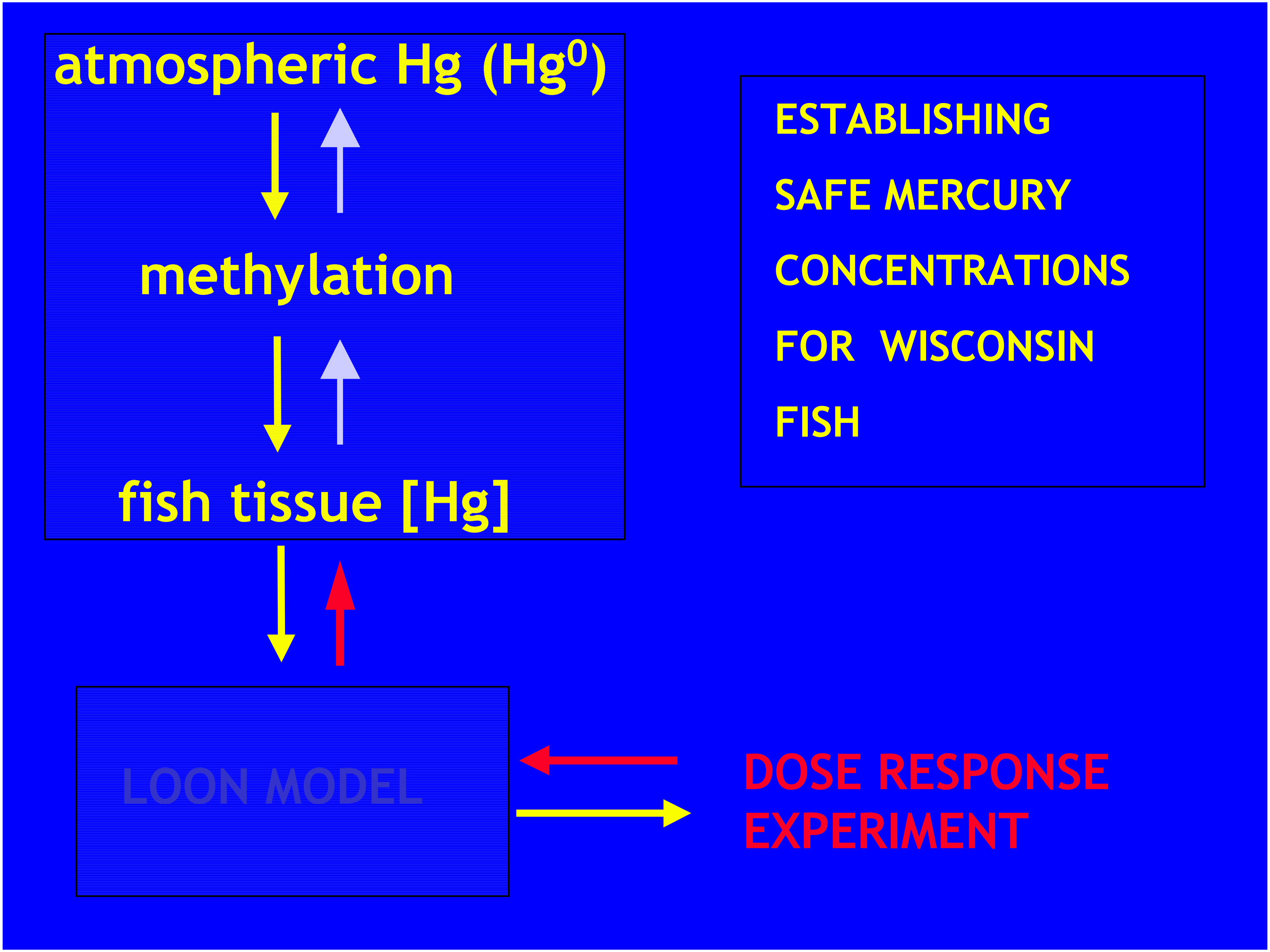
LOON MODEL

WITH

R-MCM MODEL

LOON MODEL

Loon blood and tissue [Hg]


atmospheric Hg (Hg^0)
methylation
fish tissue [Hg]
LOON MODEL
ESTABLISHING SAFE MERCURY CONCENTRATIONS FOR WISCONSIN FISH
DOSE RESPONSE EXPERIMENT

Objective 1: mechanistic model

- mercury uptake
- mercury assimilation
- mercury excretion

"Black box"

- rate of food intake
- mercury content of food

field

- assimilation of mercury
- rate of excretion
- tissue partitioning

laboratory

Rate of food intake

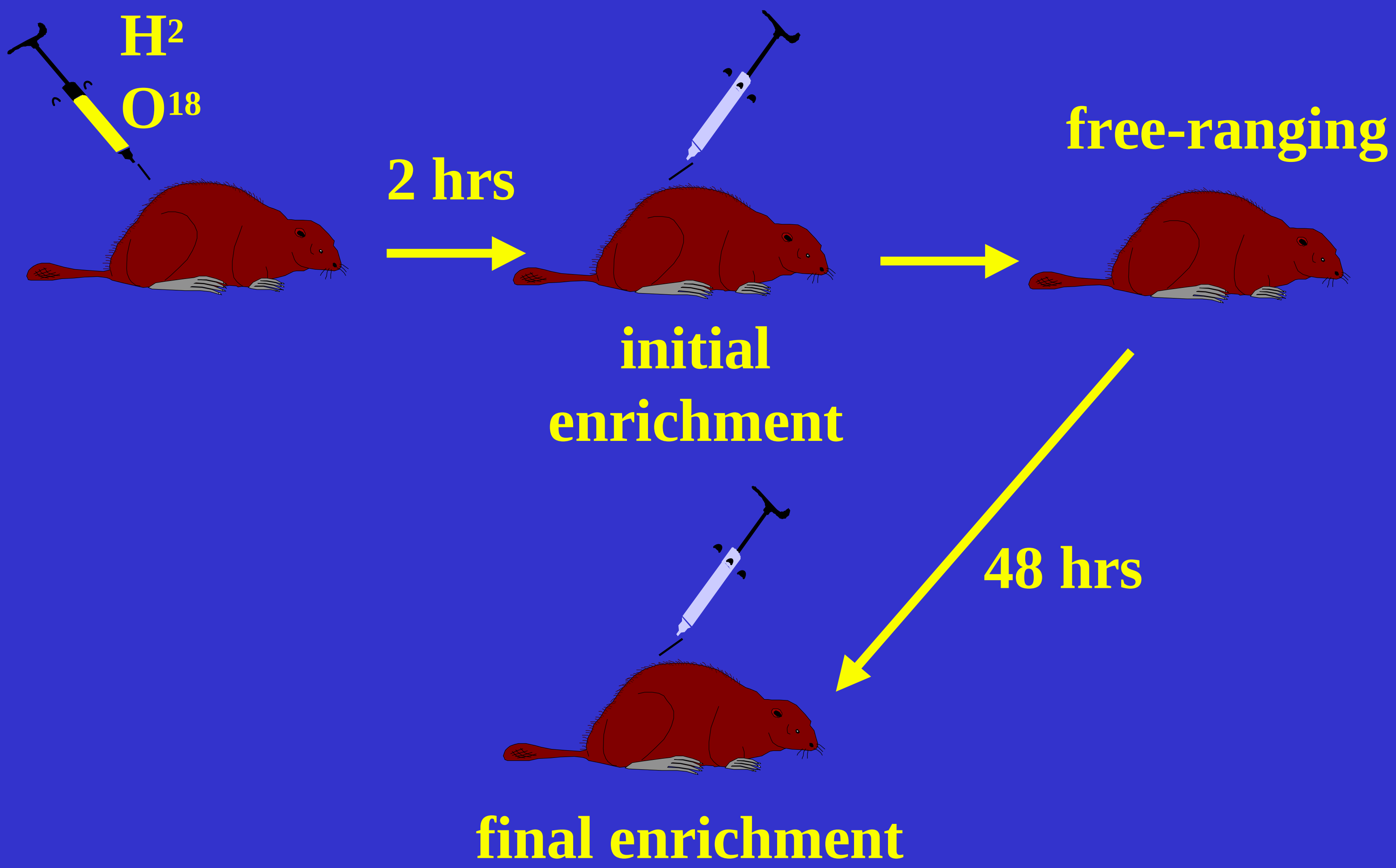
$$\text{intake} = \text{respiration} + \text{production}$$

- based on total energy budget
- measured with doubly labeled water

Doubly labeled water (HH^2O^{18})

- label the body water pool
- H leaves the body as water
- O leaves the body as water and CO_2
- the ratio of turnover of H and O gives the amount of CO_2 produced

Doubly labeled water

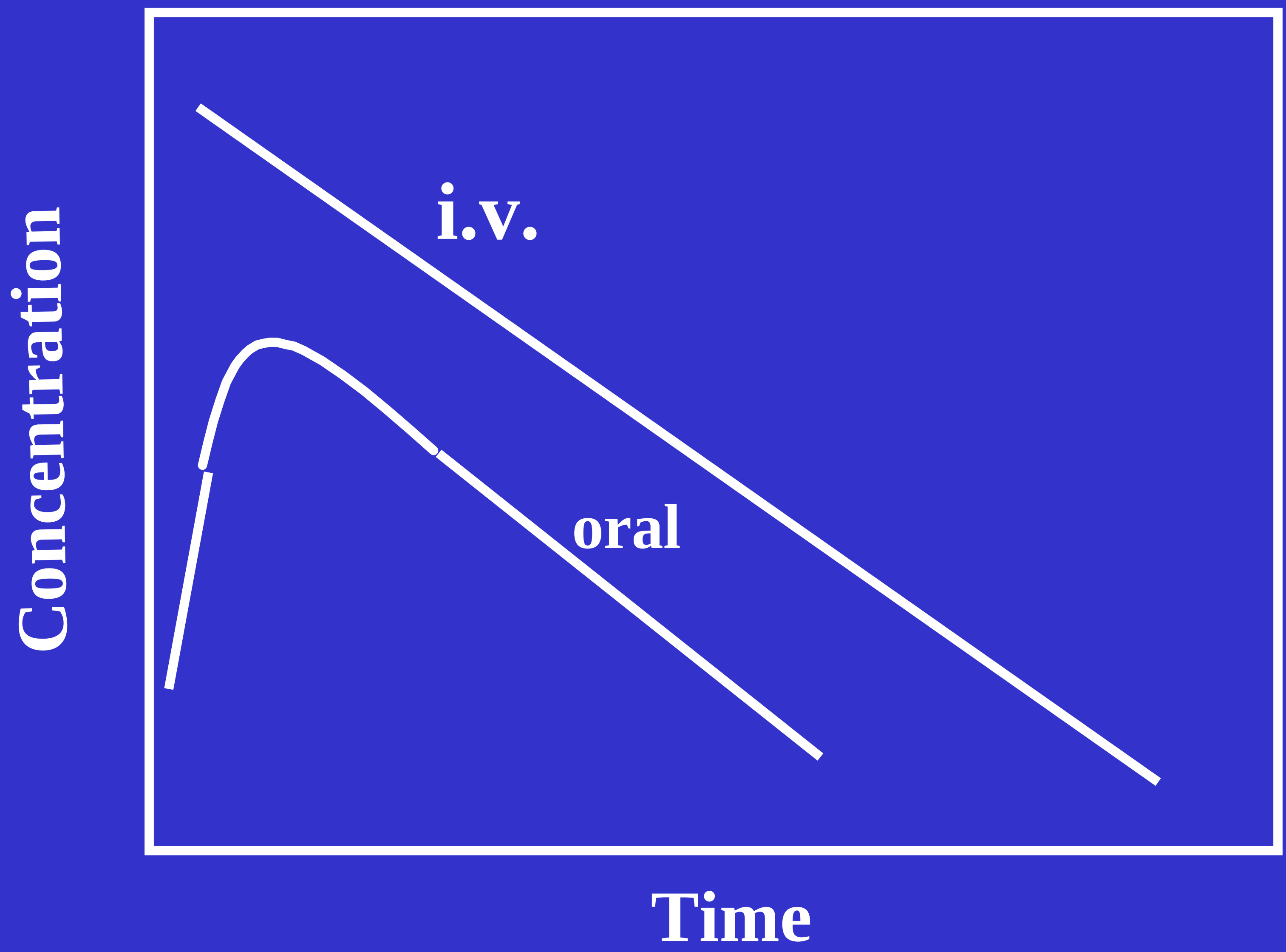


Bioavailability and excretion

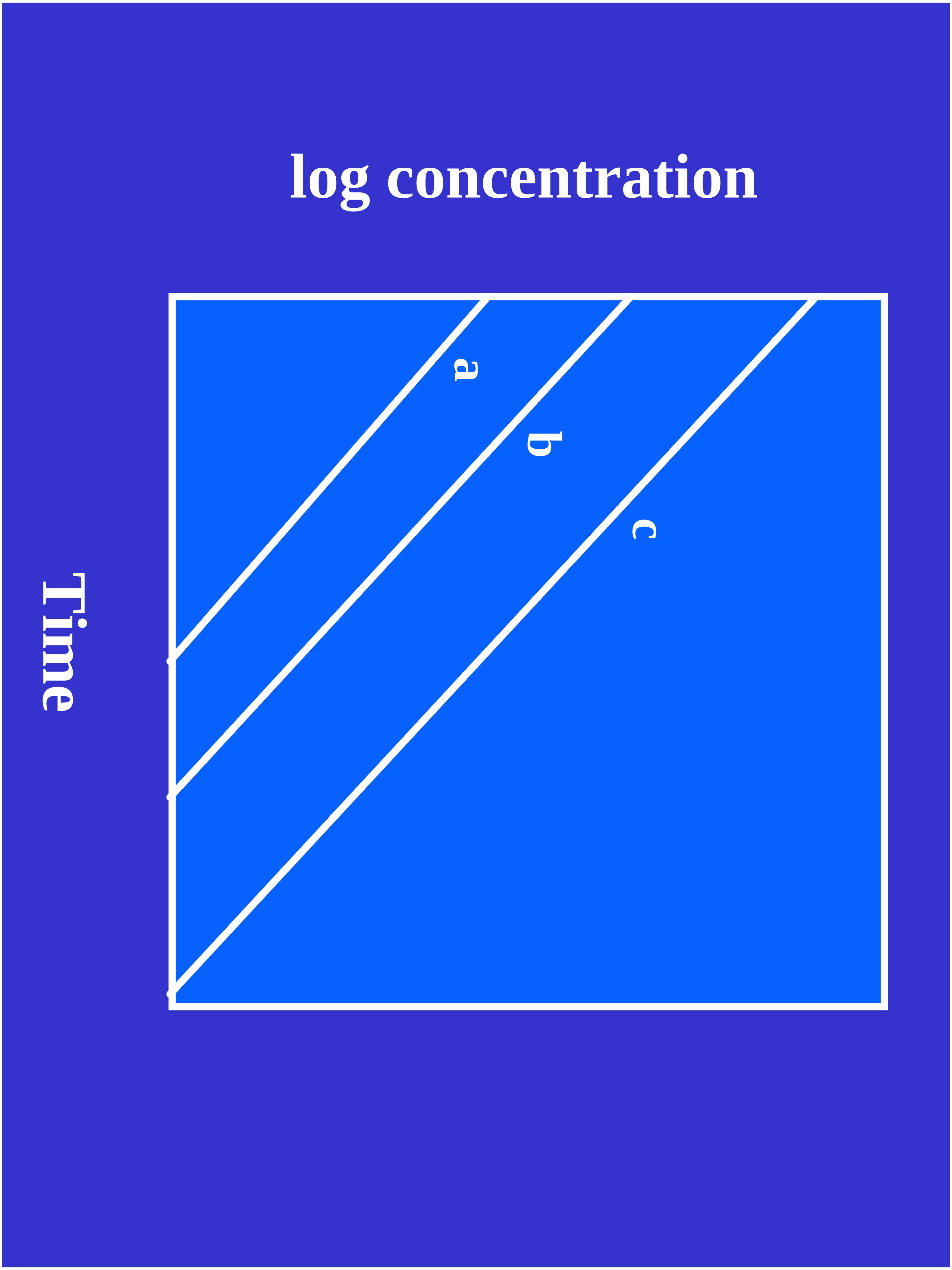
- administer single pulse dose
- intravascular and oral routes
- monitor concentration in blood over time
- determine bioavailability and excretion

Methods

- collect eggs from nests (n = 8)
- incubate and hatch at UMESC
- assign chicks to groups (4/group)
- blood collection



i.v.
oral
Concentration
Time


log concentration
Time
a
b
c

Bioaccumulation model

$$C_t = \frac{\alpha R C_f}{k_e}\left(1 - e^{-k_e t}\right) + C_0 e^{-k_e t}$$

C_t = total body burden (µg/g)

α = bioavailability

R = daily rate of food intake (g food/g loon x day)

C_f = mercury content of food (µg/g)

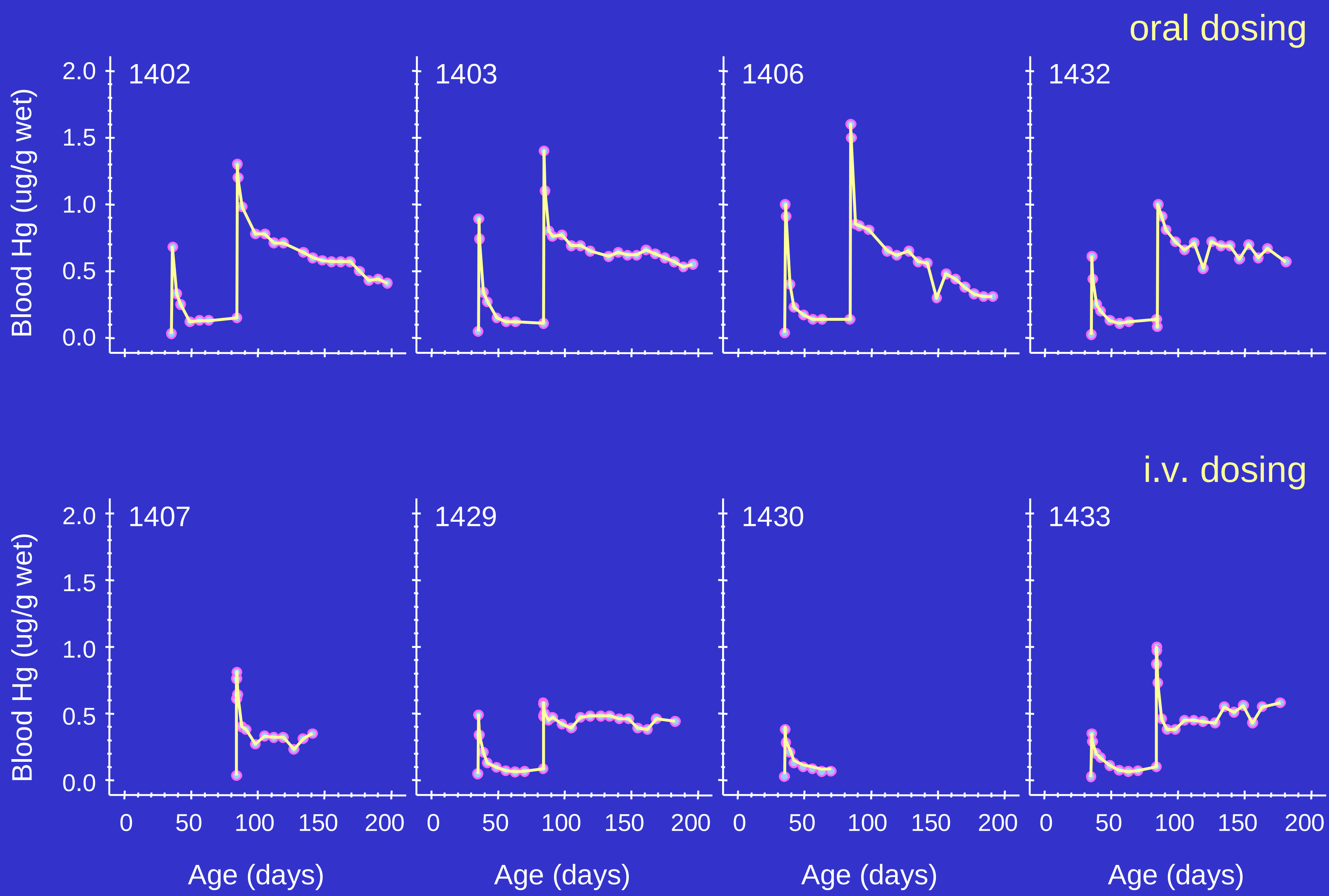
k_e = excretion rate constant (day^{-1})

C_0 = initial body burden (µg/g)

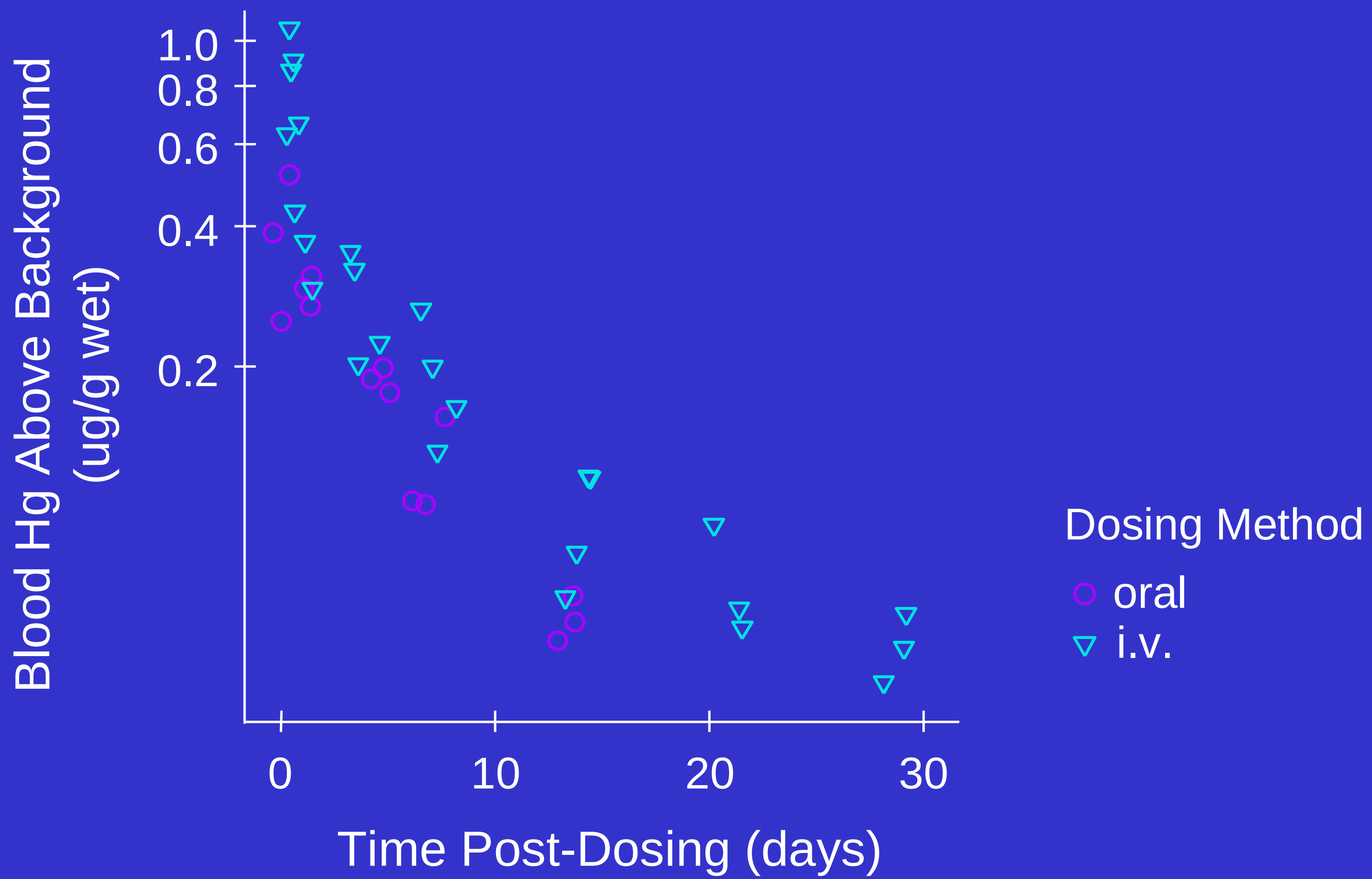
Energy and Food Requirements

Chick Age (d)	DEE (kJ/d)	Food intake (g/d)
10	645	144
21	721	160
35	1819	406

Sequential Blood Hg Levels of Eight Common Loons Dosed Orally or Intravenously



Measurement of Bioavailability of Methyl Mercury in Common Loon Chicks



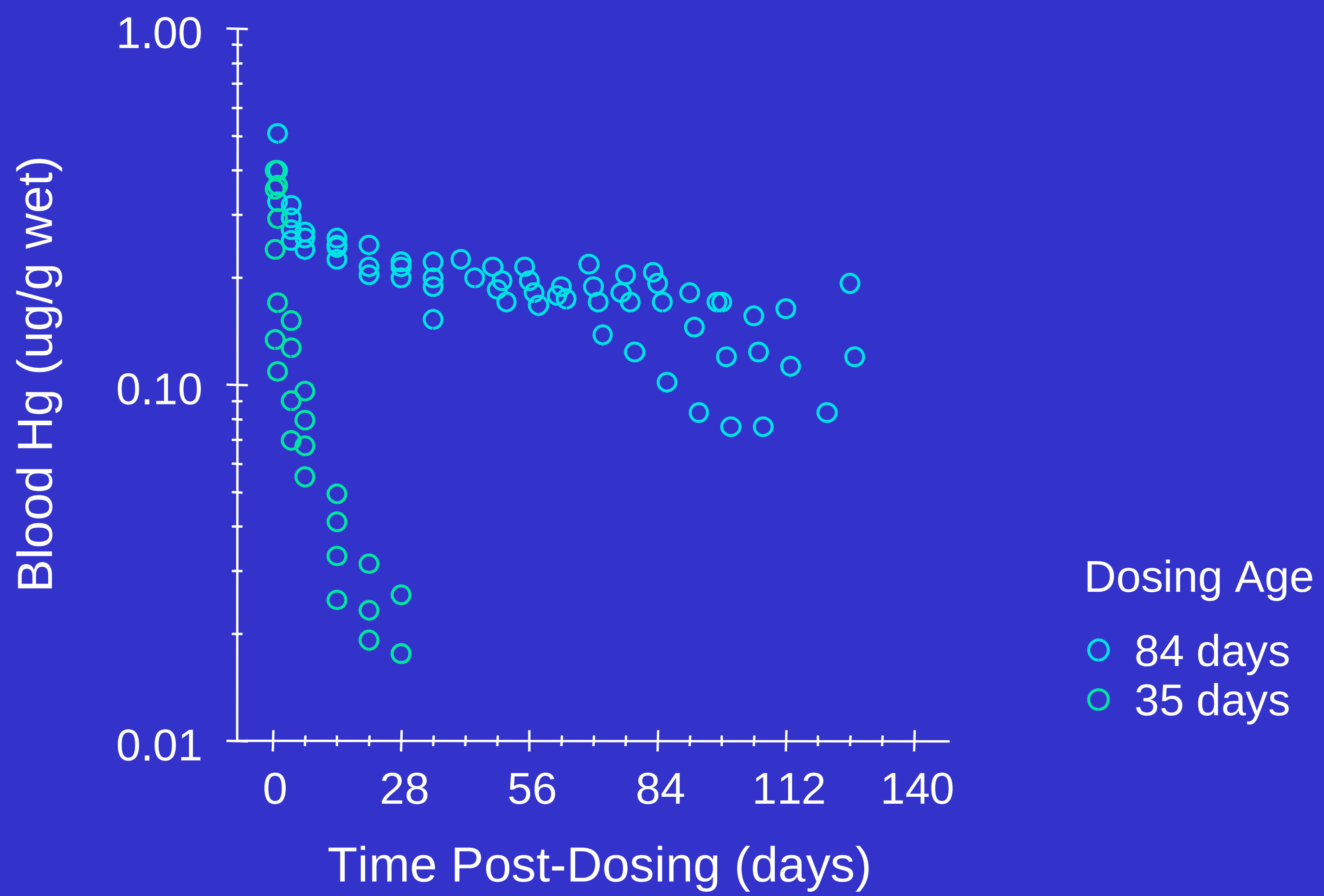
Bioavailability

$$f = \frac{AUC_{oral}}{AUC_{iv}}$$

AUC = (area under the curve)

81% MeHg Bioavailability

Hg Elimination by Common Loon Chicks Varies with Age



Major Findings on Absorption and Elimination of Methyl mercury

- 81% of ingested methyl mercury is absorbed
- during feather growth the half-life for elimination is 3-10 days
- after completion of feather growth, half-life for elimination is >100 days

Bioaccumulation model

$$C_t = \frac{\alpha R C_f}{k_e}\left(1 - e^{-k_e t}\right) + C_0 e^{-k_e t}$$

C_t = total body burden (μg/g)

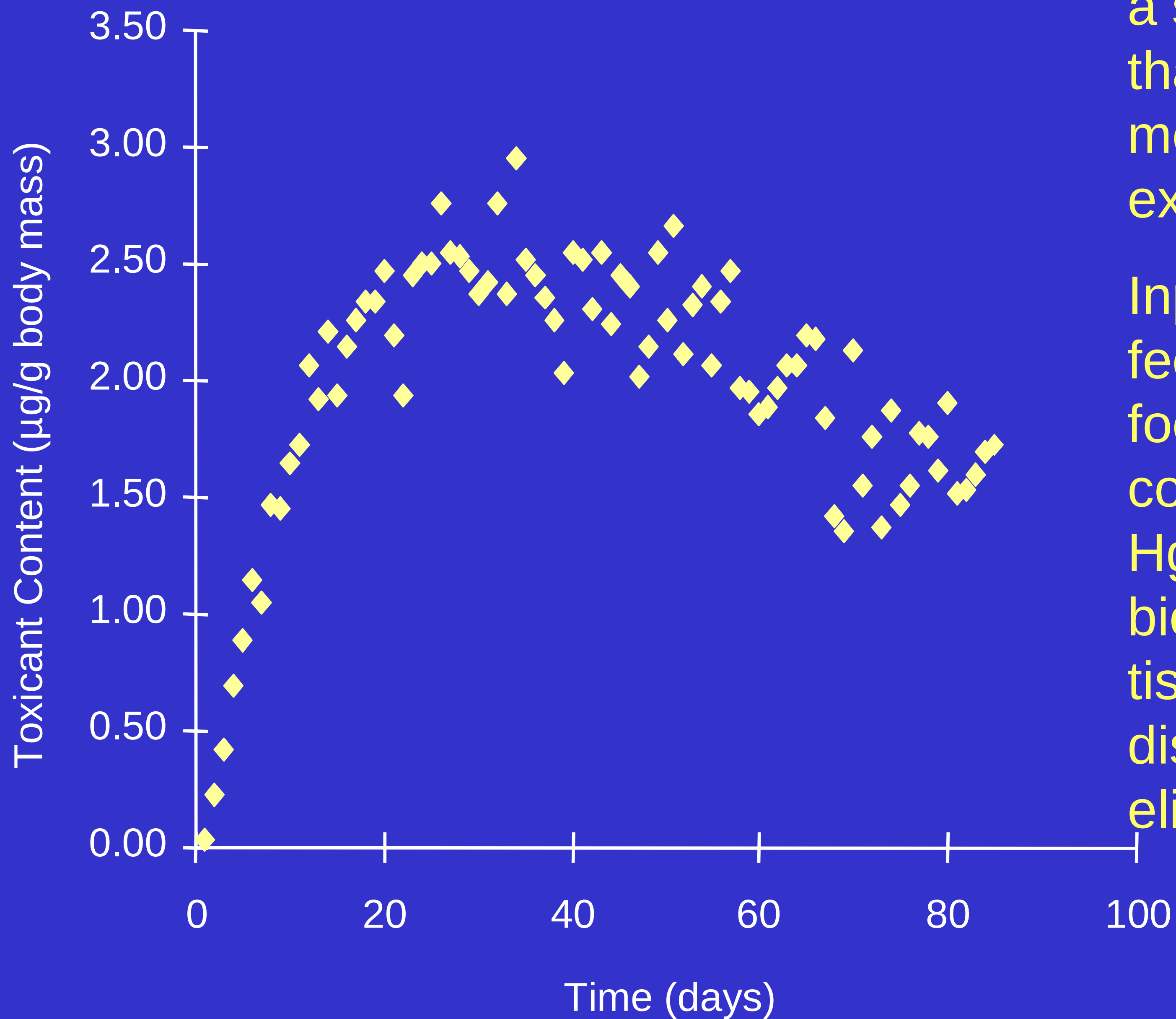
α = bioavailability

R = daily rate of food intake (g food/g loon x day)

C_f = mercury content of food (μg/g)

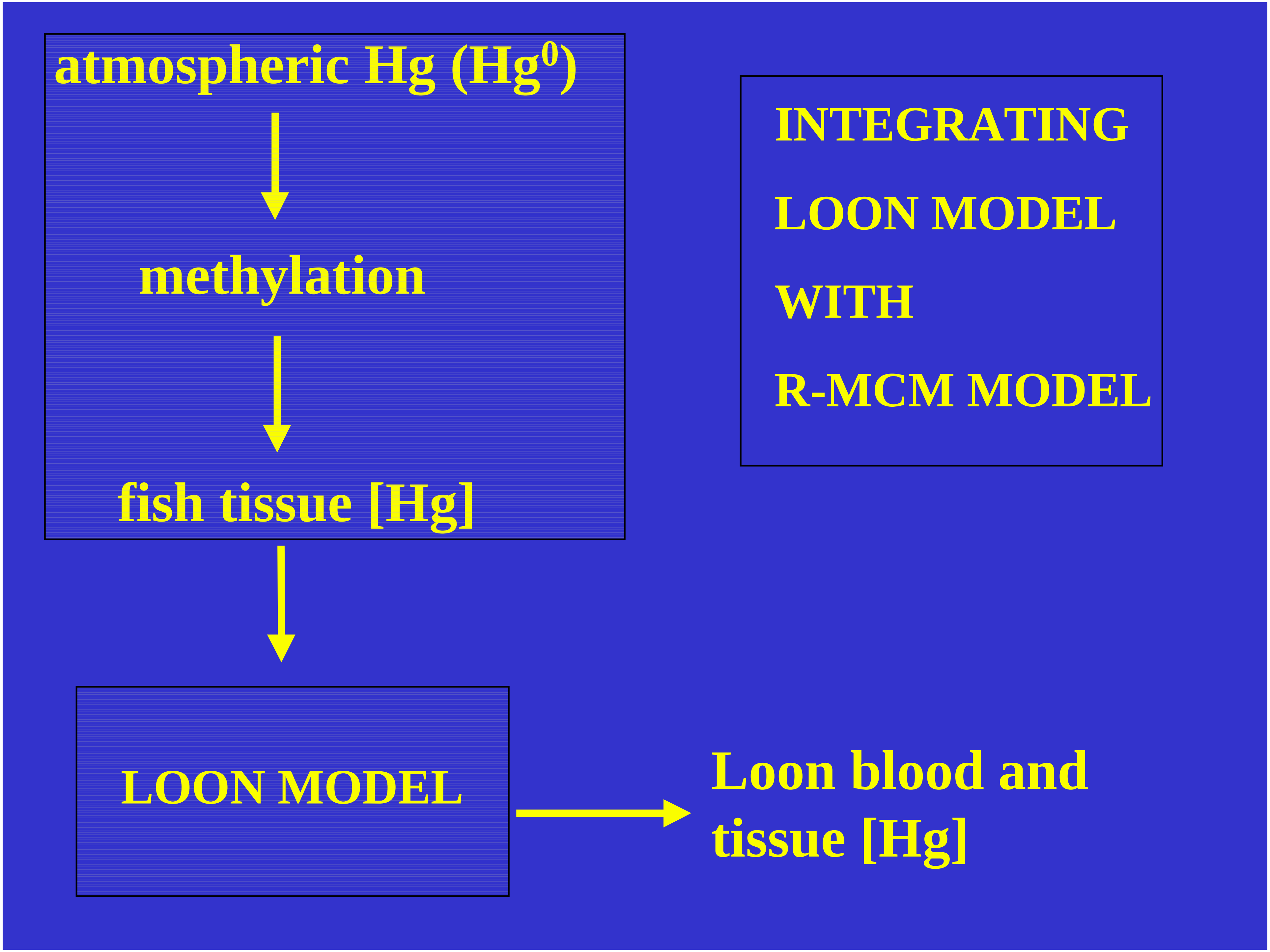
k_e = excretion rate constant (day^{-1})

C_0 = initial body burden (μg/g)



Goal:
a simple model that predicts mercury exposure

Inputs:
feeding rate, food Hg concentration, Hg bioavailability, tissue distribution, Hg elimination


atmospheric Hg (Hg^0)
methylation
fish tissue [Hg]
INTEGRATING
LOON MODEL
WITH
R-MCM MODEL
LOON MODEL
Loon blood and tissue [Hg]

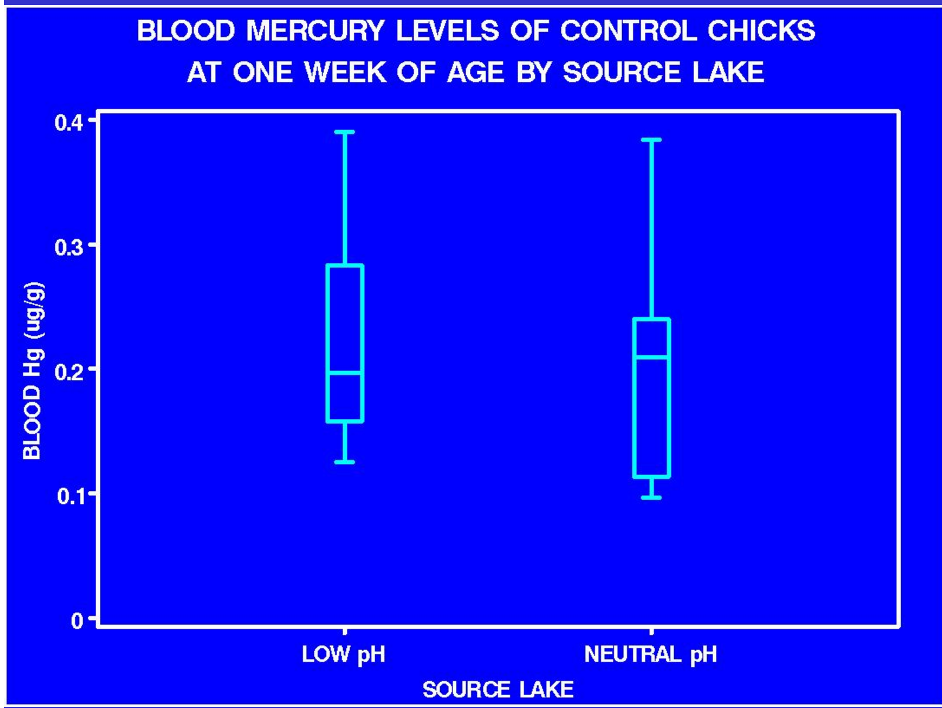
Objective 2: dose-response

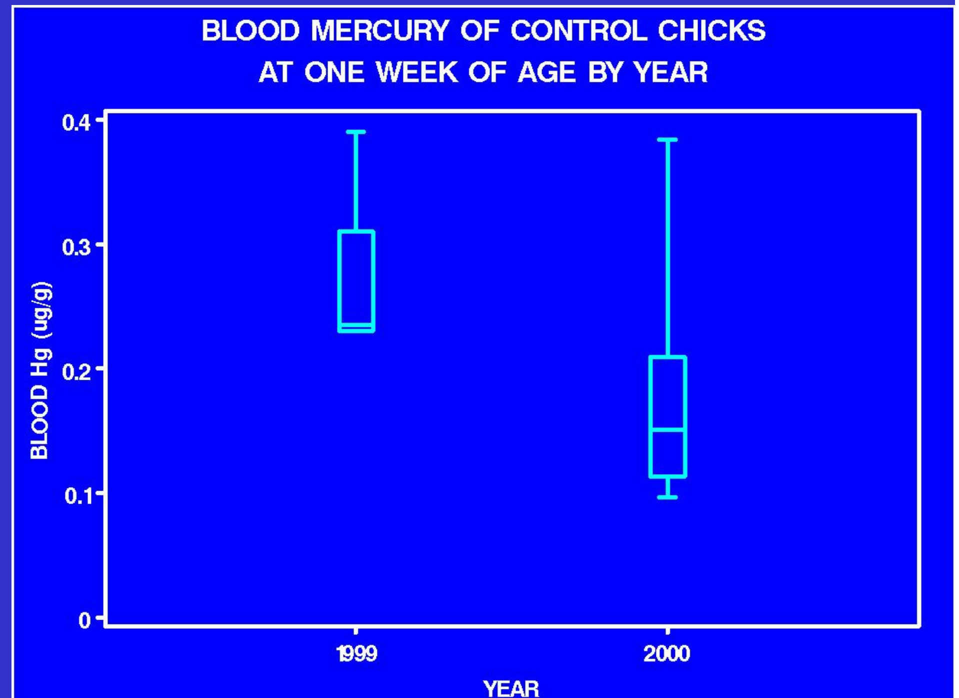
- level of MeHg that reduces survival and fitness
- chronic exposure experiment
- physiological and histological endpoints
- behavioral assays

Methods

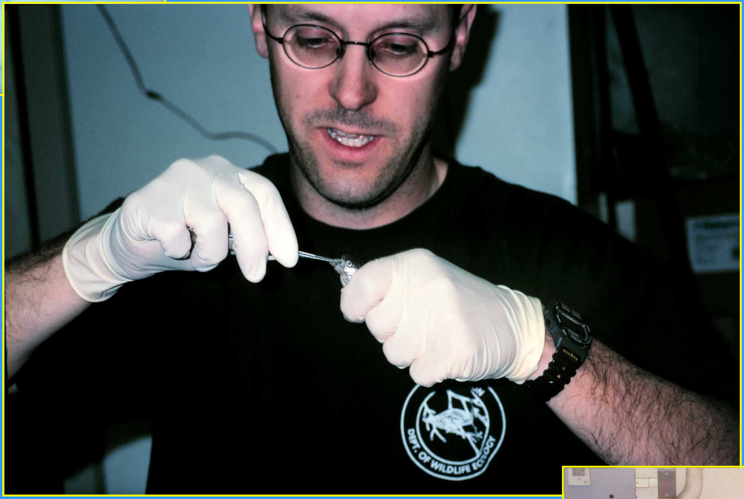
- collect eggs from 2 lake classes
- incubate and hatch at UMESC
- assign to 4 groups (4/raceway)
- daily dosing
- blood collection
- euthanize birds and collect organs and tissues

Chronic Exposure for 105 days


BLOOD MERCURY LEVELS OF CONTROL CHICKS
AT ONE WEEK OF AGE BY SOURCE LAKE
BLOOD Hg (ug/g)
0.4
0.3
0.2
0.1
0
LOW pH
NEUTRAL pH
SOURCE LAKE


BLOOD MERCURY OF CONTROL CHICKS
AT ONE WEEK OF AGE BY YEAR
BLOOD Hg (ug/g)
0.4
0.3
0.2
0.1
0
1999
2000
YEAR

Daily methylmercury dose (control, 0.1 µg/g, 0.5 µg/g, or 1.5 µg/g) was based on food intake



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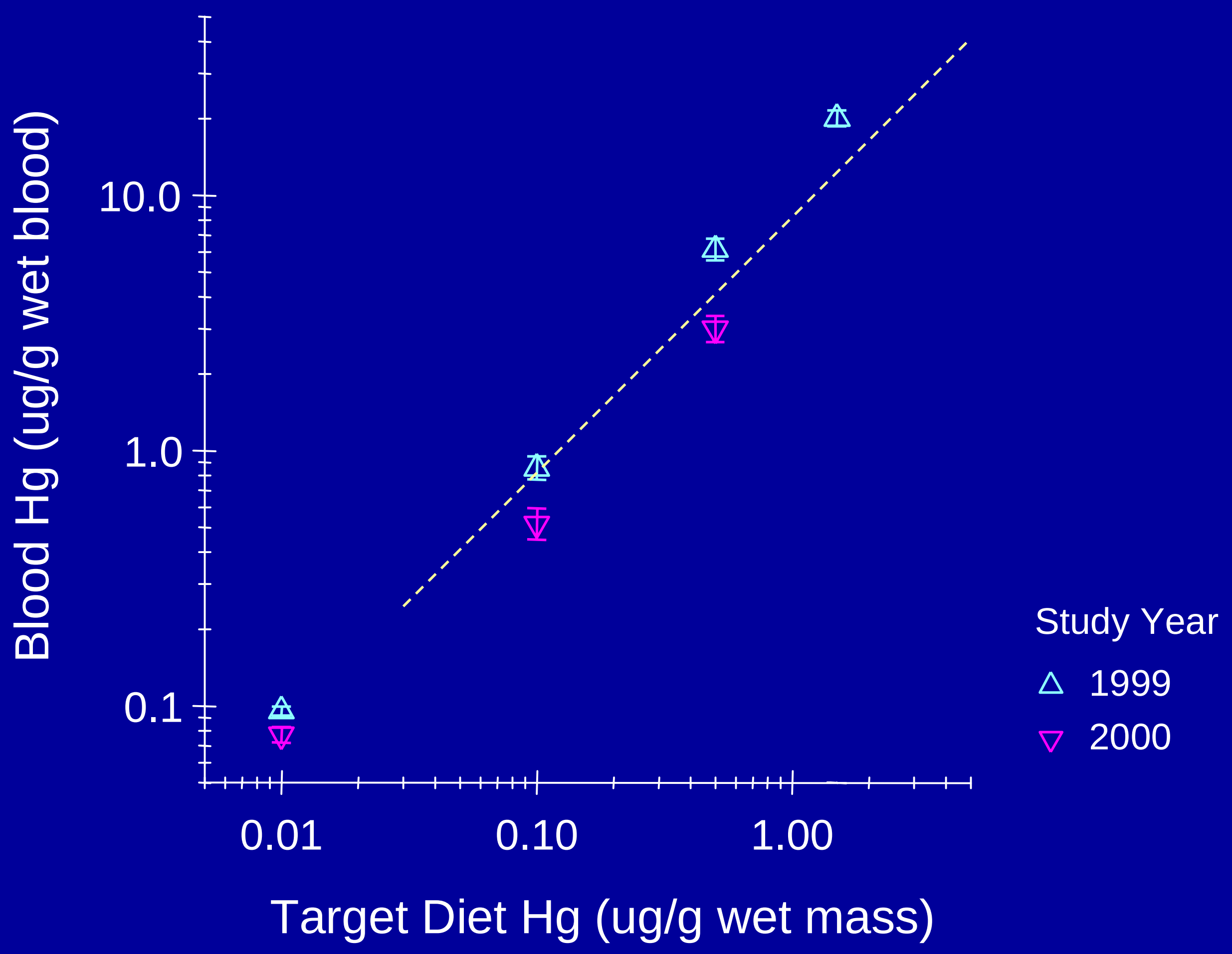
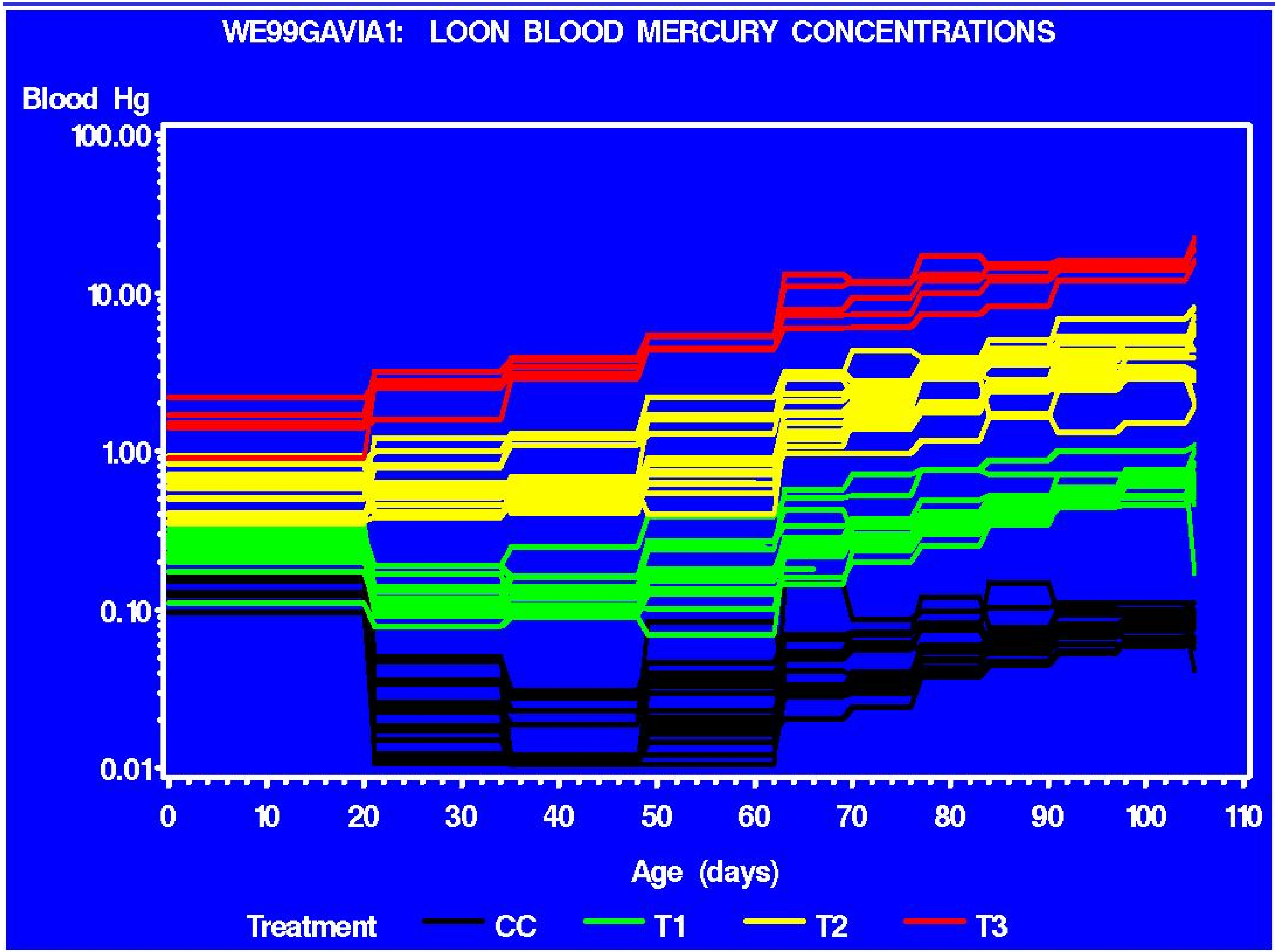
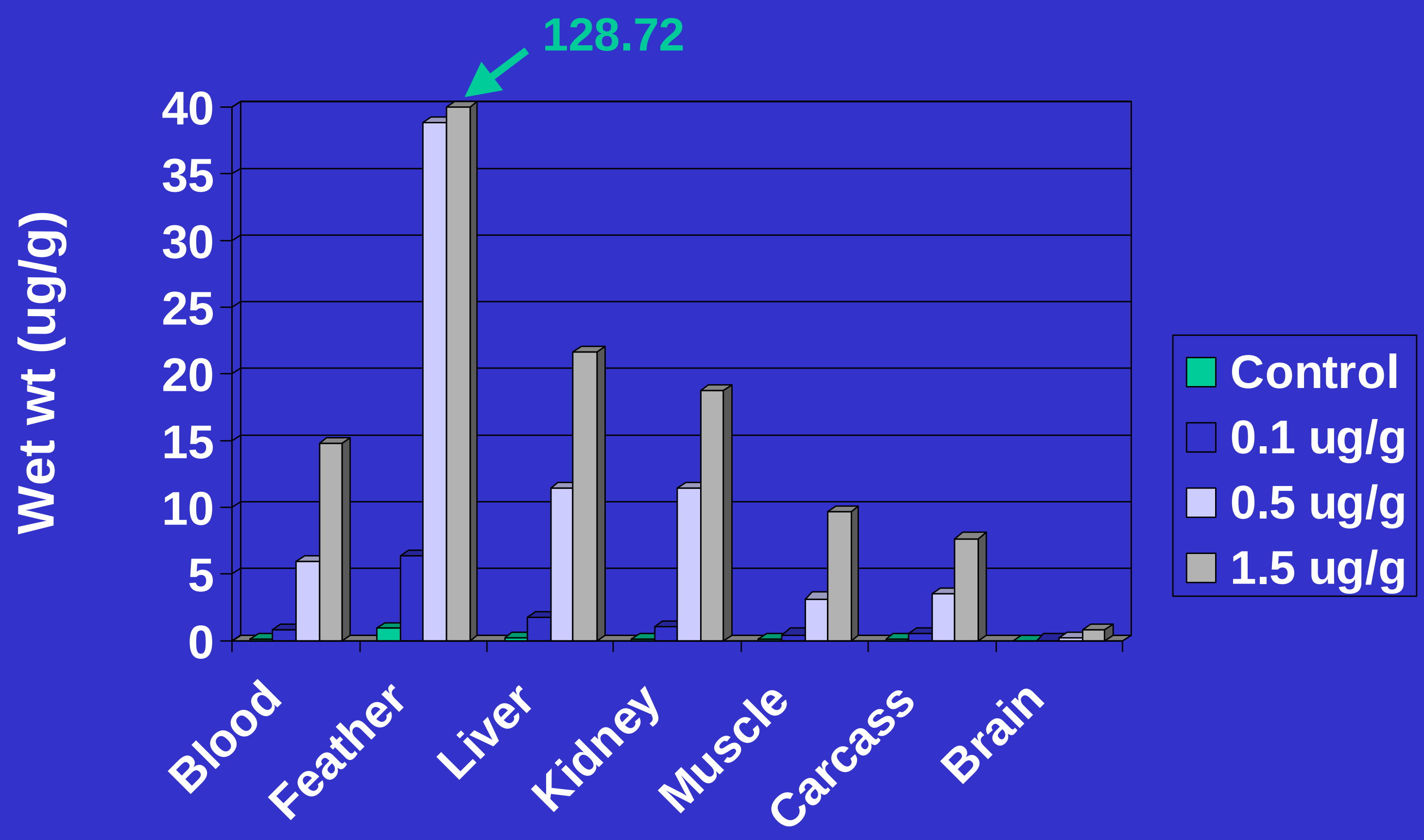
Dose-Response : Blood Hg at 15 Weeks



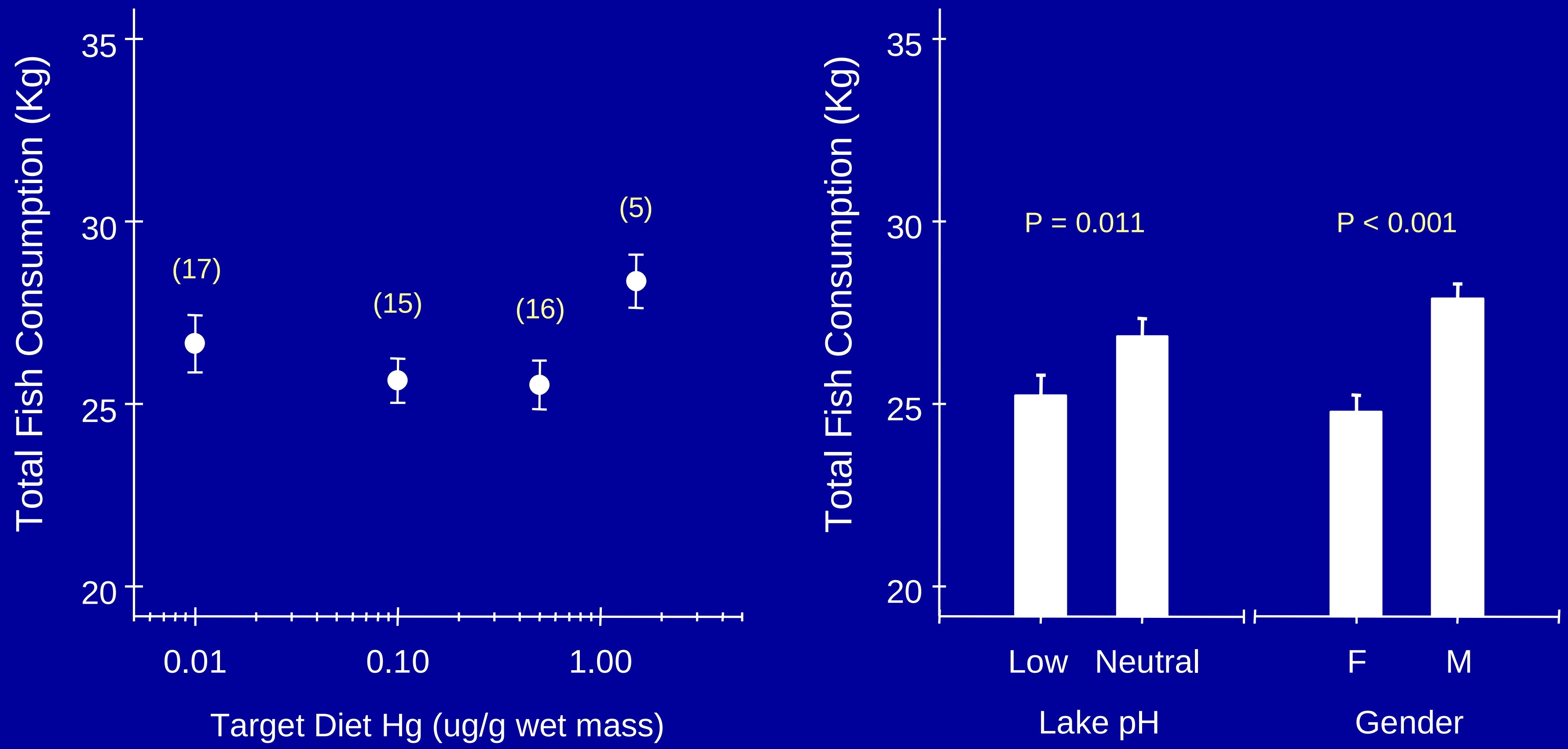


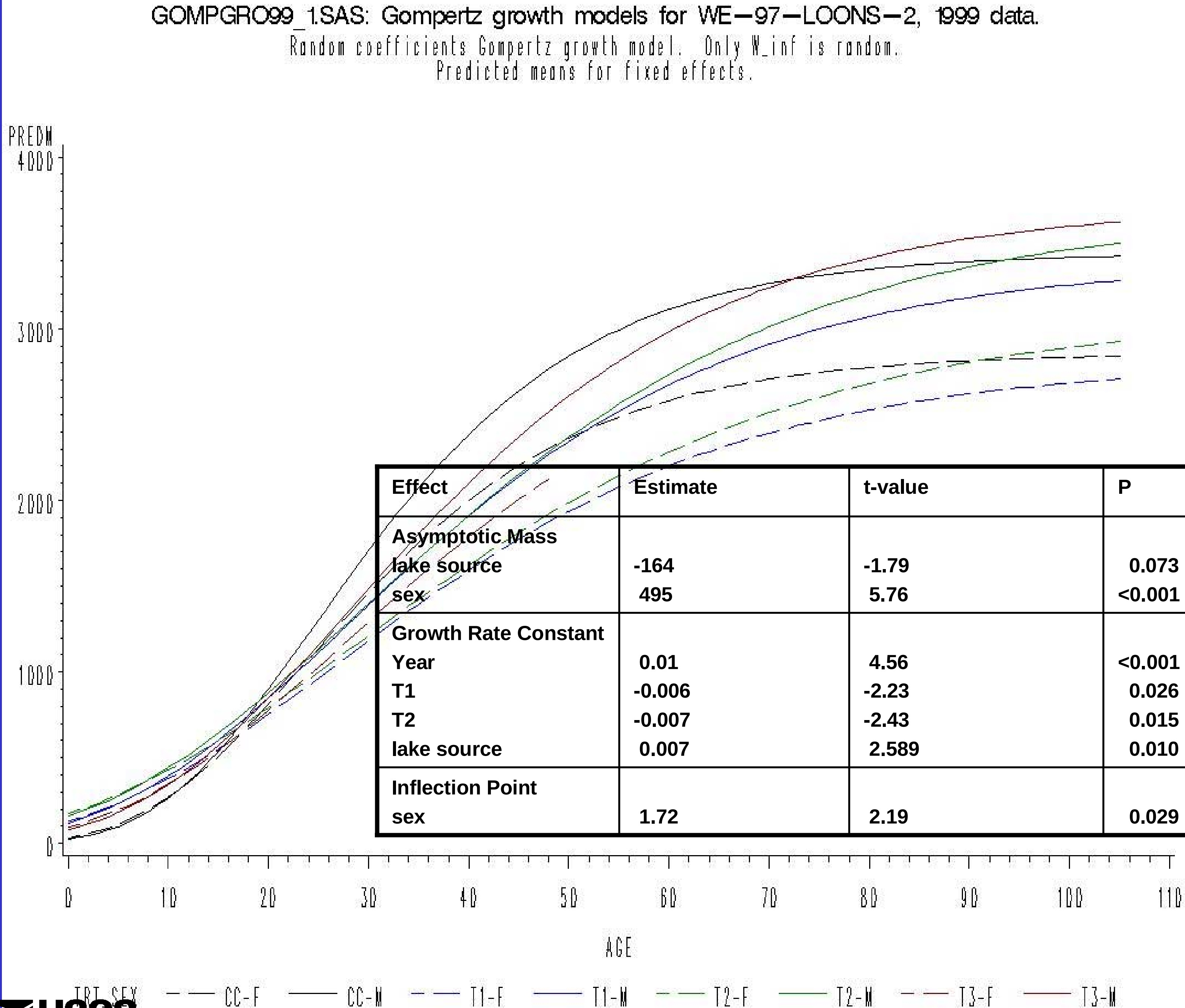
WE99GAVIA1: LOON BLOOD MERCURY CONCENTRATIONS
Blood Hg
100.00
10.00
1.00
0.10
0.01
0
10
20
30
40
50
60
70
80
90
100
110
Age (days)
Treatment
CC
T1
T2
T3

Hg Residue Levels (ug/g) in Common Loon Tissues (1999)



Dose-Response: Fish Consumption Over 15 Weeks (preliminary)





Effect	Estimate	t-value	P
Asymptotic Mass			
lake source	**-164**	**-1.79**	**0.073**
sex	**495**	**5.76**	**<0.001**
Growth Rate Constant			
Year	**0.01**	**4.56**	**<0.001**
T1	**-0.006**	**-2.23**	**0.026**
T2	**-0.007**	**-2.43**	**0.015**
lake source	**0.007**	**2.589**	**0.010**
Inflection Point			
sex	**1.72**	**2.19**	**0.029**

Physiological Endpoints

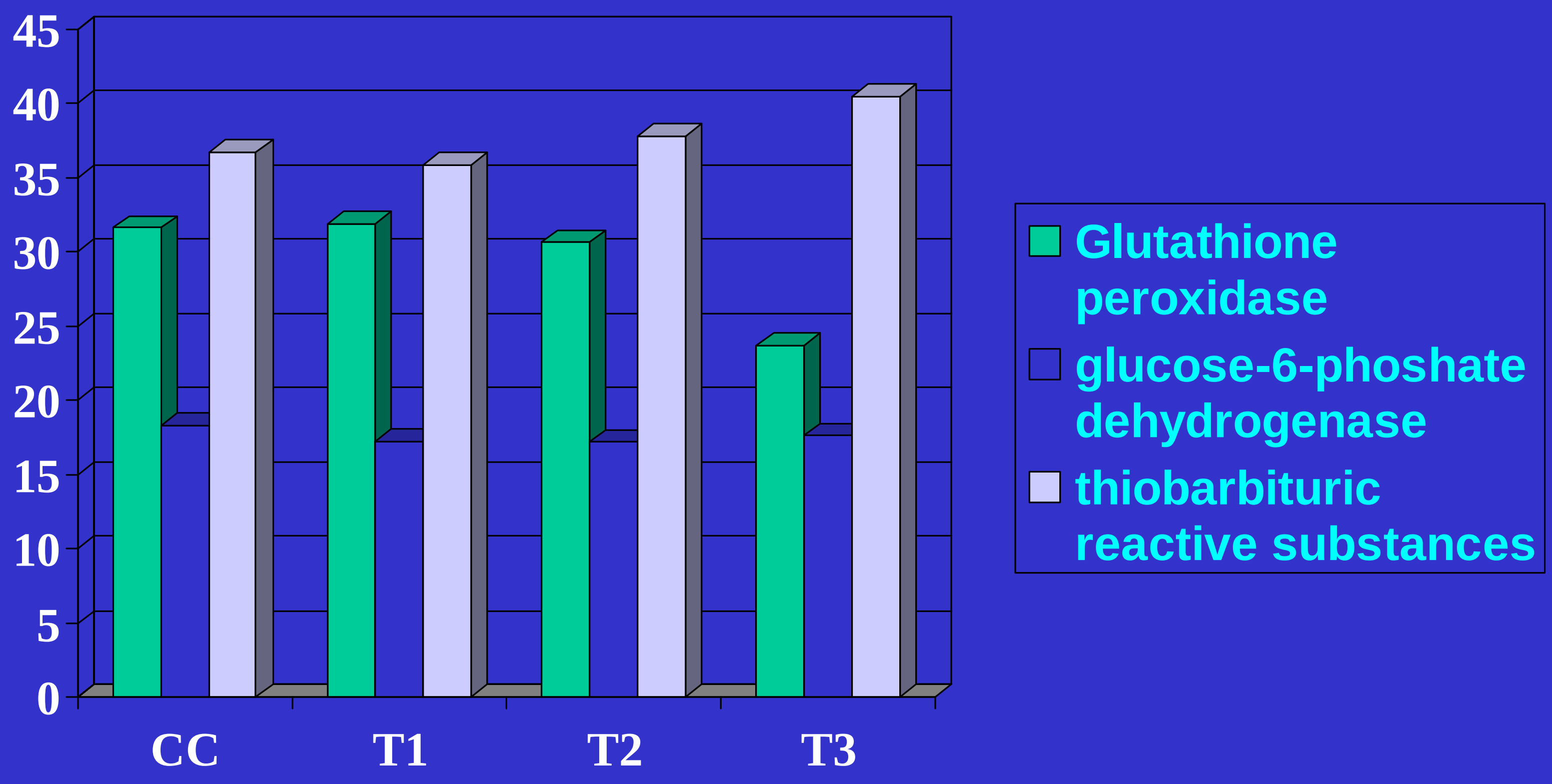
Blood and tissue residue levels

Blood and tissue oxidative stress

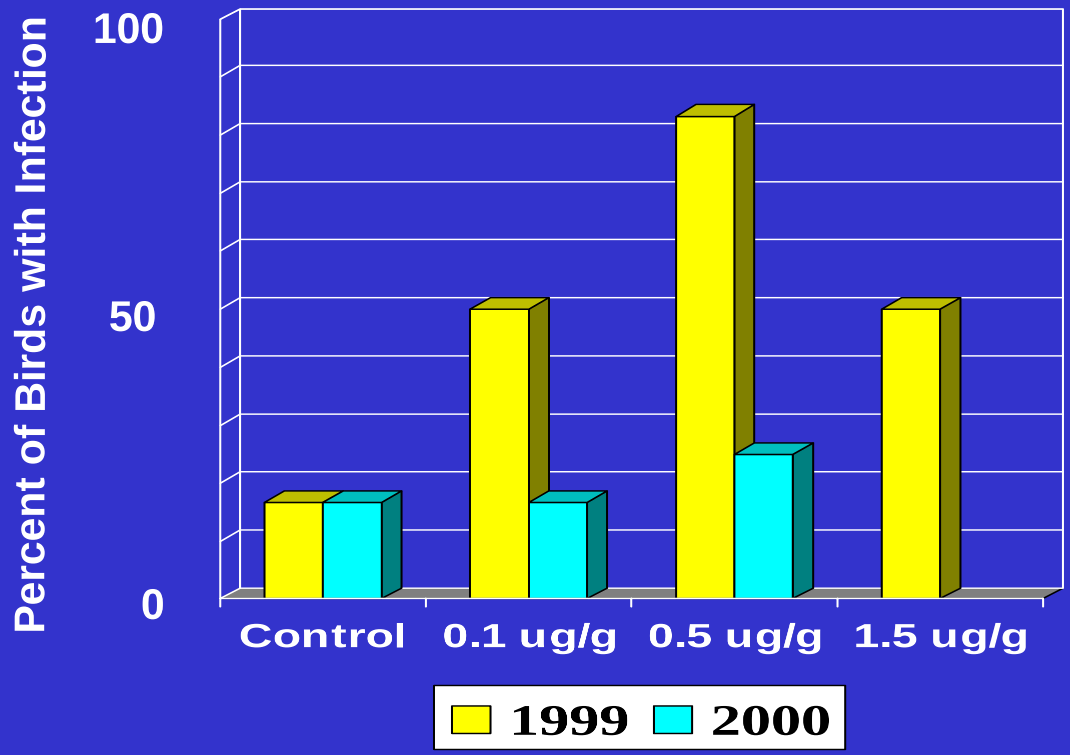
DNA damage

Immune function

Mean Oxidative Stress Enzyme Levels: Brain (1999)



Incidence of Bacterial Infection



1999 vs 2000: 50 vs 19.4%, χ^2=6.213, P=0.013

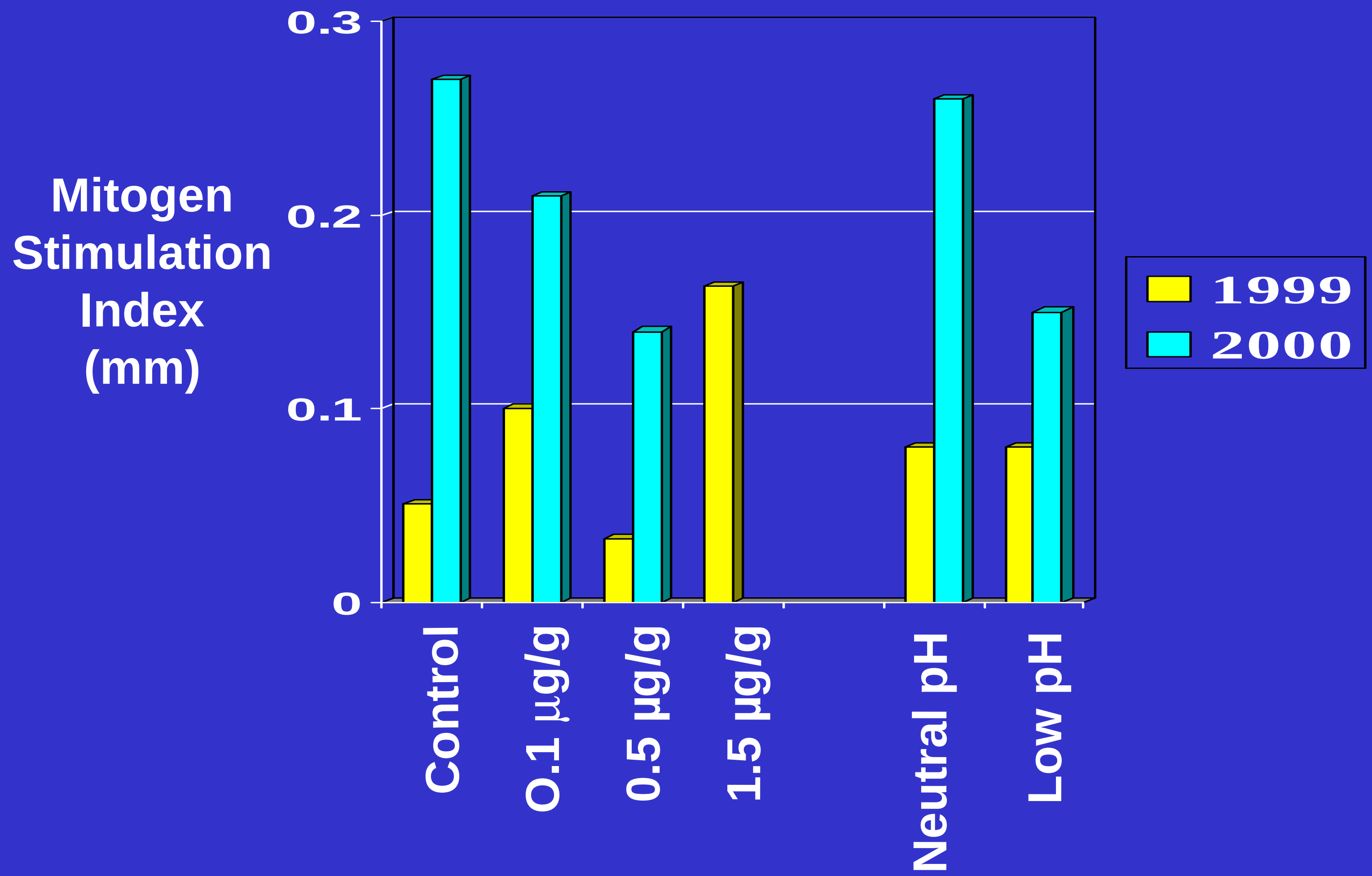
1999 (trtmnt * infection): χ^2=5.333, P=0.149

2000 (trtmnt * infection): χ^2=0.355, P=0.837

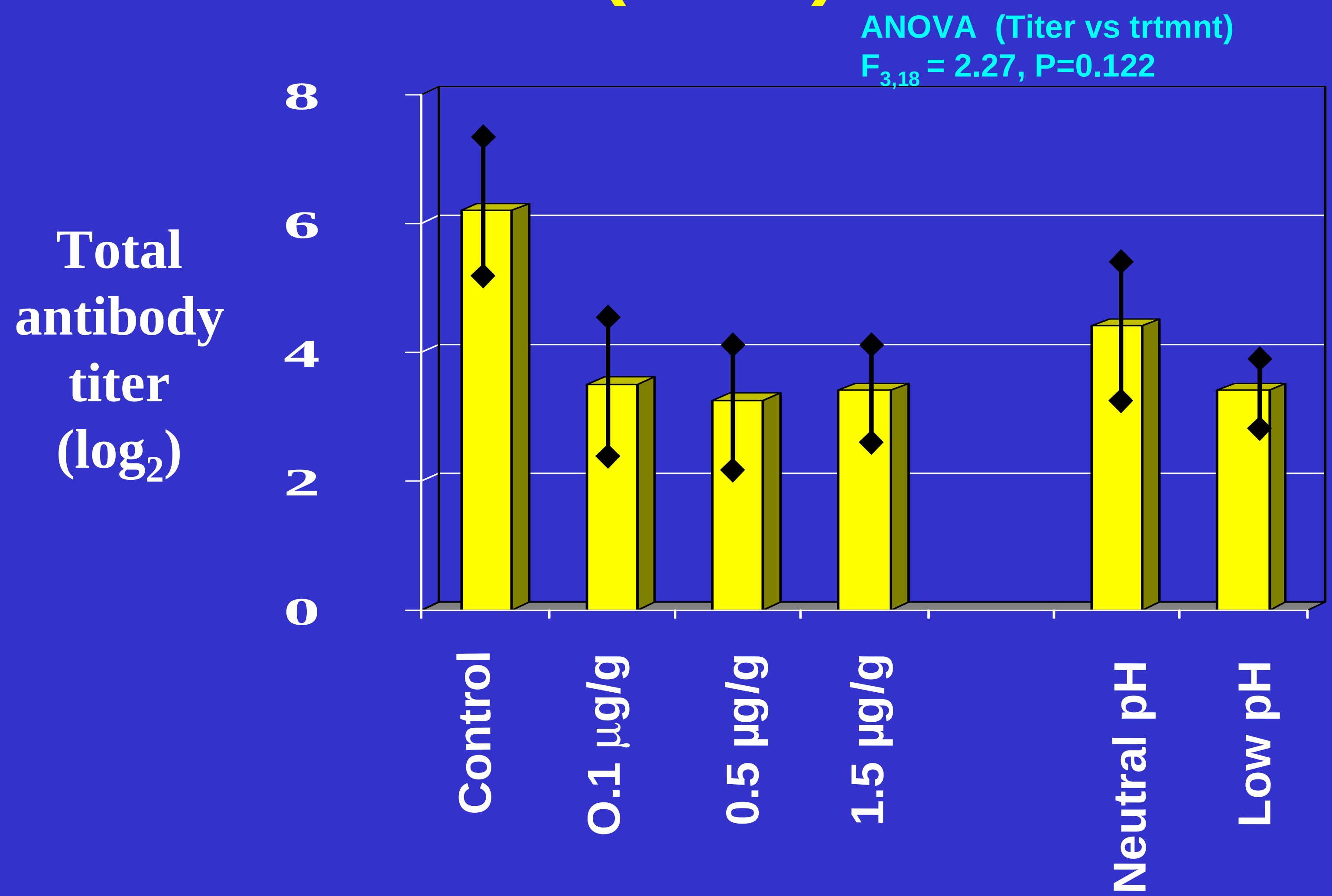
99/00 (trtmnt * infection): χ^2=4.288, P=0.232

Mean PHA-P Skin Response

2000 (*source* * MSI): $F_{1,28}$ = 2.98, P = 0.0945



Mean Primary Antibody Response (1999)

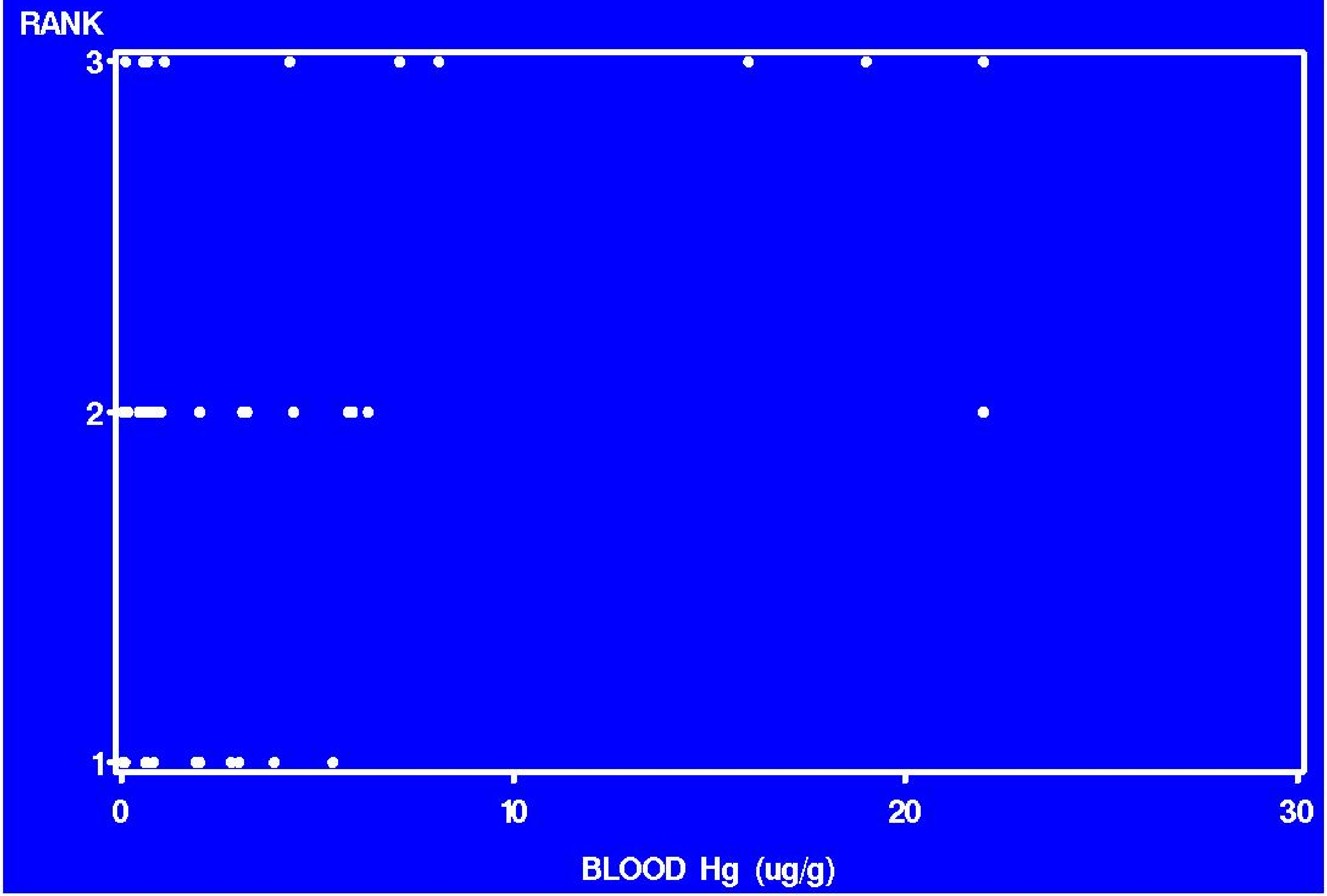


Histological Endpoints

liver
spleen
bone marrow
bursa
thymus
adrenal gland
thyroid
gonad

pancreas
muscle
CNS
brachial nerve
sciatic nerve
brain
lung
kidney

ASSESSMENT OF BRACHIAL NERVE SHEATH INTEGRITY



Radio-telemetry

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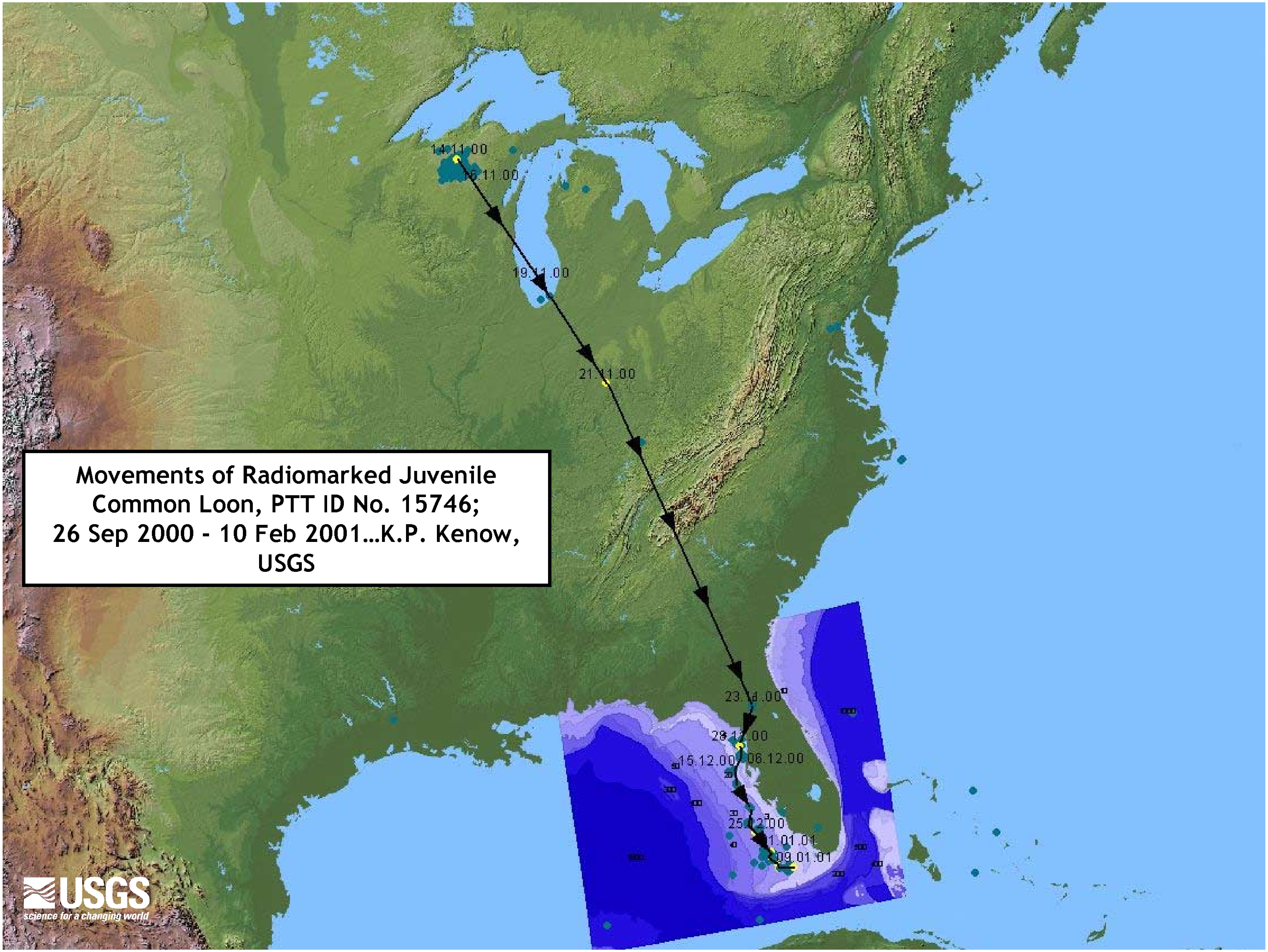
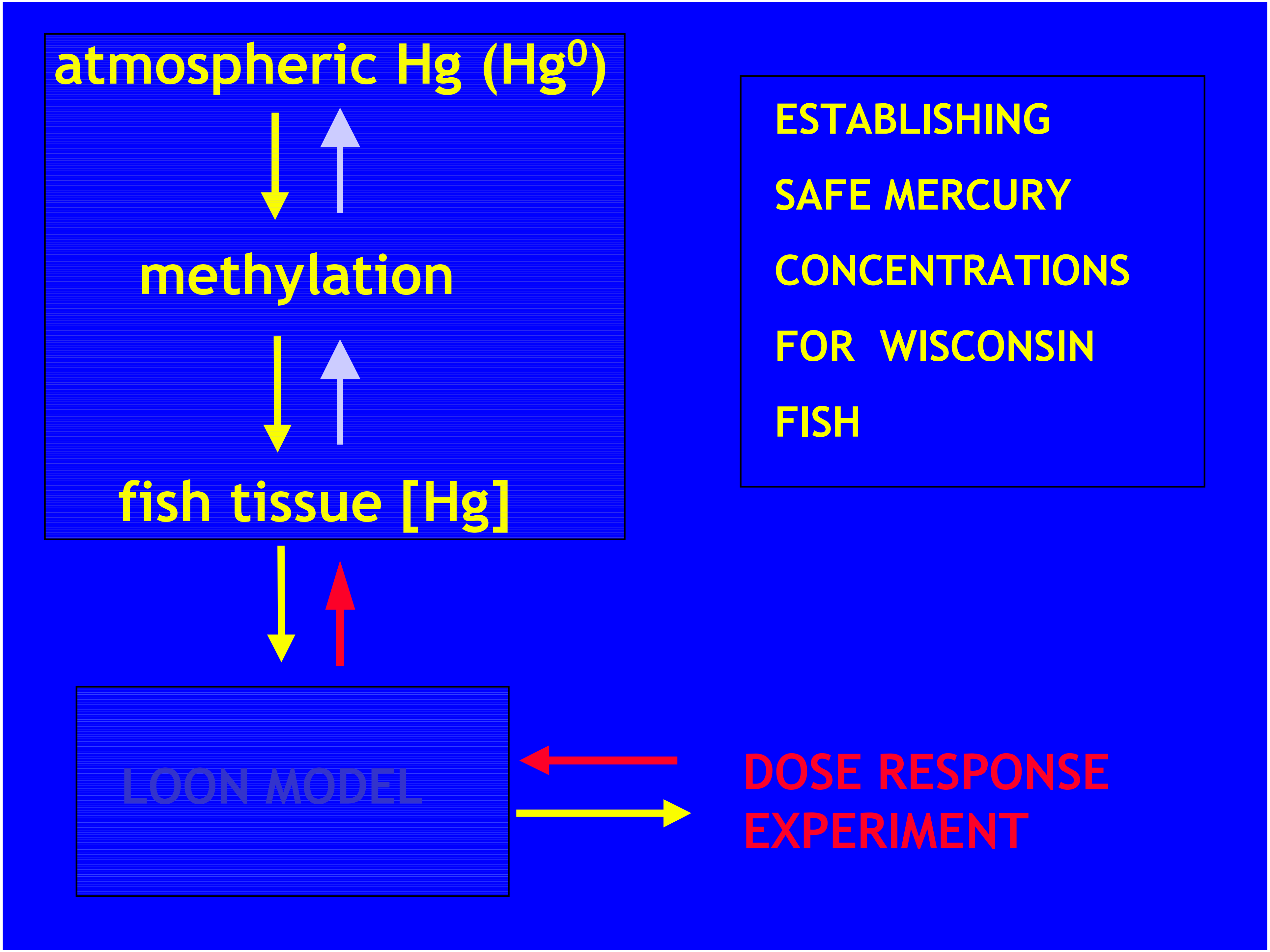


Movements of Radiomarked Juvenile Common Loon, PTT ID No. 15746; 26 Sep 2000 - 10 Feb 2001…K.P. Kenow, USGS


atmospheric Hg (Hg0)
methylation
fish tissue [Hg]
LOON MODEL
ESTABLISHING SAFE MERCURY CONCENTRATIONS FOR WISCONSIN FISH
DOSE RESPONSE EXPERIMENT

Summary: Common loons & Hg

- Kinetics of Hg absorption and elimination have been described
- In conjunction with field feeding rates and fish Hg levels, we should be able to predict exposure
- Dose-response studies should enable us to predict effects over ecologically relevant exposure levels
- Because of dosing irregularities, we have yet to establish an accurate relationship between mercury intake and blood mercury exposure

- Results of the dose-response work so far are inconclusive with respect to whether the current exposure levels in WI negatively impact loon chick health
  - No impact on survival and no overt signs of neurotoxicity
  - Suppression of instantaneous growth rate at lower treatments but not at high treatment level
  - No indication of behavioral effects with Hg exposure
  - No convincing negative physiological or histological findings
  - Analytical power associated growth and immune function measures may be insufficient to detect differences at the resulting sample sizes
- Lake pH is an important ecological confounding factor that may cause effects correlated with Hg exposure

Proposed Workplan 2002

- Establish accurate relationship between Hg intake and blood Hg exposure
- Validate predictions of the pharmacokinetic model
- Integrate loon model with R-MCM
- Additional tissue partitioning data
- Increase sample size to increase power of analyses of growth and immune function assays
- WDNR/USGS budget - $ 200k
- Tetra-Tech, Inc. budget - ?

Collaborators

- Wisconsin DNR
- USGS/BRD UMESC
- UW-Madison Dept. of Wildlife Ecology
- Tetra Tech Inc.
- USGS/BRD PWRC
- Texas A&M Univ.
- Wright State Univ.
- University of Florida

Funding Sources

- Electric Power Research Institute
- Wisconsin Utilities Association
- Wisconsin DNR
- USGS/BRD UMESC
- University of WI
- Water Environmental Resource Foundation

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